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NEW RECORDS OF LICHENS FROM TASMANIA, PRINCIPALLY FROM THE 2018 TMAG EXPEDITION OF DISCOVERY TO MUSSELROE BAY

by Gintaras Kantvilas, Brian J. Coppins, Patrick M. McCarthy and John A. Elix

(with two plates)

Kantvilas, G., Coppins, B.J., McCarthy, P.M. & Elix, J.A. 2020 (9:xii). New records of lichens from Tasmania, principally from the 2018 TMAG Expedition of Discovery to Musselroe Bay. *Papers and Proceedings of the Royal Society of Tasmania* 154: 1–8. Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Box 5058, UTAS LPO, Sandy Bay, Tasmania 7005, Australia (GK). Royal Botanic Garden Edinburgh, 20A Inverleith Row, Edinburgh, EH3 5LR, United Kingdom (BJC). 64 Broadsmith St, Scullin, A.C.T. 2614, Australia (PMMcC). Research School of Chemistry, Building 137, Australian National University, Canberra, A.C.T. 2601, Australia (JAE). Author for correspondence: Email: Gintaras.Kantvilas @tmag.tas.gov.au

Nineteen lichen species are recorded for the first time from Tasmania: *Amandinea conranensis* Elix & P.M.McCarthy, *Bacidia laurocerasi* (Delise ex Duby) Zahlbr., *Buellia extenuatella* Elix & Kantvilas, *Catinaria atropurpurea* (Schaer.) Vězda & Poelt, *Collema crispum* (Huds.) Weber ex F.H.Wigg., *Diploschistes euganeus* (A.Massal.) J.Steiner, *D. gyrophoricus* Lumbsch & Elix, *Endocarpon crassisporum* P.M.McCarthy & Filson, *Gyalecta pellucida* (Coppins & Malcolm) Baloch & Lücking, *Lecanora pseudogangaleoides* Lumbsch subsp. *pseudogangaleoides*, *L. strobilina* (Spreng.) Kieff., *Opegrapha niveoatra* (Borrer) J.R.Laundon, *O. spodopolia* Nyl., *O. varia* Pers., *Physcia austrostellaris* Elix, *Ramonia absconsa* (Tuck.) Vězda, *Trapelia concentrica* Elix & P.M.McCarthy and *Xanthoparmelia xerica* (Elix) Elix. The new combination *Austroparmelina corrugativa* (Kurok. & Filson) Elix & Kantvilas is proposed and *Austroparmelina euplectina* (Kurok. ex Elix). A.Crespo *et al.* is reduced to synonymy. The salient morphological and anatomical features, ecology and distribution are discussed for each species.
Key Words: lichenised fungi, taxonomy, floristics, *Austroparmelina*.

INTRODUCTION

Since the first checklists of Tasmanian lichens, for example those of Wetmore (1963), which listed 421 taxa, Kantvilas (1989: 633 taxa) and Kantvilas (1994: 762 taxa), the number of lichens recorded for Tasmania has risen steadily and now stands at 1309 (McCarthy 2020). The increases have been derived from taxonomic revision of existing herbarium collections, fortuitous and *ad hoc* collecting, as well as targeted studies of particular locations (e.g. Jarman & Kantvilas 1994, Kantvilas *et al.* 2012), vegetation types (Jarman & Kantvilas 1995, Kantvilas & Jarman 2012) and taxonomic groups (e.g. Kantvilas 2012, Kantvilas & Coppins 2019). More recently, a formal survey program, the Tasmanian Museum and Art Gallery Expeditions of Discovery, has been initiated with the express aim of, *inter alia*, discovering new or hitherto overlooked species in Tasmania. The first of these expeditions, undertaken in 2017 in the Little Swanport area on Tasmania's east coast (Baker *et al.* 2019), proved exceptionally productive for lichens. Of the 170 species recorded, two were described as new to science (Elix *et al.* 2019a, McCarthy & Kantvilas 2018) and a further 19 were new records for Tasmania (Elix *et al.* 2019b, Baker *et al.* 2019); additional putative new taxa await further study. The second expedition was undertaken in late 2018 to the Cape Portland–Musselroe Bay area in the far northeast of Tasmania. Lichens again proved to be a rich source of novelties and, whereas an inventory of species will be presented elsewhere, new records for Tasmania are documented here. As with previous accounts of this nature, some of the discoveries arose entirely from fieldwork conducted during the expedition. In other cases, the expedition identification work prompted a broader investigation of herbarium collections, and the novelties in question were found to be represented by additional specimens from other Tasmanian localities. It is particularly noteworthy that two of the new records are of species previously known only from their respective type collections: *Ramonia absconsa* (from South Carolina, U.S.A.) and *Xanthoparmelia xerica* (from South Australia).

MATERIAL AND METHODS

The study is based chiefly on material collected by the first author during the TMAG Expedition of Discovery at Musselroe Bay, northeastern Tasmania, during November 2018, and a second, follow-up field trip in September 2019. Specimens are housed in the Tasmanian Herbarium (HO), with selected duplicates sent to other herbaria as indicated in the text. Additional reference herbarium material, chiefly from HO, was also consulted. Anatomical and morphological observations were undertaken using light microscopy, with thin hand-cut sections mounted in water, 10% KOH (K), lactophenol cotton blue, Lugol's iodine after pre-treatment with dilute KOH, 50% HNO_3 (N) and ammoniacal erythrosin. Routine chemical analyses using thin-layer chromatography follow standard methods (Elix 2014). Nomenclature of lichen asci mainly follows Hafellner (1984). Ascospore measurements are presented either in the format: 5th percentile–*average*–95th percentile, with outlying values given in brackets and *n* being the number of measurements, or as a simple range.

THE SPECIES

Amandinea conranensis Elix & P.M.McCarthy

Characterised by a crustose thallus not containing any substances detectable by thin-layer chromatography, black apothecia 0.1–0.3 mm wide, 1-septate, *Buellia*-type ascospores, 9–14 × 5–8 µm, constricted at the septum when older, and filiform conidia, 12–21 × 0.7–1 µm (see Elix *et al.* 2017). It is most similar to the common *A. punctata* (Hoffm.) Coppins & Scheid., which has larger ascospores (10–20 × 5–9 µm) that do not become constricted. The Tasmanian specimen was collected from a fencepost in a paddock. The species also occurs in Victoria and New South Wales where it is an epiphyte in coastal situations.

TASMANIA: Cape Portland, Musselroe Wind Farm, Tregaron Lagoons, vicinity of Turbine D8, 40°47'38"S 148°05'24"E, 30 m alt., 10 Sep. 2019, G. Kantvilas 256/19 (HO).

Austroparmelina corrugativa (Kurok. & Filson) Elix & Kantvilas comb. nov. MycoBank No. MB834192

Parmelia corrugativa Kurok. & Filson, *Bull. Natl Sci. Mus.* ser. B, 1: 38 (1975); *Pseudoparmelia corrugativa* (Kurok. & Filson) Hale, *Smithsonian Contr. Bot.* 31: 25 (1976); *Canoparmelia corrugativa* (Kurok. & Filson) Elix & Hale, *Mycotaxon* 27: 278 (1986). Type: South Australia: near Balhannah, 3 June 1966, R.W. Rogers 553 (holo– MEL!).

Parmelina euplectina Kurok. ex Elix, *Mycotaxon* 47: 116 (1993); *Austroparmelina euplectina* (Kurok. ex Elix). A.Crespo, Divakar & Elix, in Crespo *et al.*, *Syst. & Biodiv.* 8: 216 (2010). Type: New South Wales: Raymond Terrace to Bulahdelah Road, N of Karuah, 9 May 1965, R.B. Filson 7176 (holo– MEL!)

With its grey foliose thallus of rather rounded, imbricate lobes containing lecanoric acid (medulla C+ red), black underside with an extensive, pale brown marginal zone, and lack of isidia or soredia, this species closely resembles the common and widespread *A. pseudorelicina* (Jatta) A.Crespo *et al.* It differs by containing the orange pigment euplectin (K+ violet), visible as a thin, orange layer in the lower part of the medulla. In Tasmania, this species occurs as an epiphyte in dry sclerophyll woodland and scrub in the northeast of the State where it is usually sympatric with *A. pseudorelicina*. It has a similar ecological distribution in southeastern Australia.

TASMANIA: Glen Esk Road near Middle Run Hill, 41°48'S 147°27'E, 220 m alt., 24 Aug. 2001, G. Kantvilas 754/01 (HO); Sawpit Hill Road, *c.* 1 km SE of Diabobble Hill, 41°31'S 147°23'E, 420 m alt., 5 Sep. 2001, G. Kantvilas 815/01 (HO); Tomahawk River, 40°52'S 147°45'E, sea-level, 1 June 2003, G. Kantvilas 108/03 (HO); Cape Portland, Musselroe Wind Farm, Tregaron Lagoons, "Copperhead Road", 40°46'49"S 147°58'00"E, 2 m alt., 9 Nov. 2018, G. Kantvilas 326/18, 328/18 (HO).

Bacidia laurocerasi (Delise ex Duby) Zahlbr.

This name has been variously applied in herbaria to specimens from Australia and elsewhere, often incorrectly. Based on the comprehensive account by Ekman (1996) and comparison with reliably identified reference specimens, it is characterised as follows:

Thallus crustose, pale brownish grey to greenish grey. Apothecia biatorine, 0.3–0.8 mm diam.; disc reddish brown to dark brown or blackish, sometimes a little piebald, matt, epruinose, plane at first, later becoming convex; proper exciple concolorous with the disc or a little paler at the upper edge, usually pale reddish brown at the sides, persistent or becoming reduced and inapparent in the oldest, most convex apothecia, in section 60–90 µm thick, colourless within, at the edges reddish brown to purplish brown, K± purplish brown, N+ orange-brown, lacking crystalline inclusions. Hypothecium 50–100 µm thick, colourless to pale yellowish, intensifying yellowish in K. Hymenium 65–85 µm thick, not inspersed, colourless, with a brown to purplish brown epihymenial layer, K+ purple-brown intensifying, N+ orange-brown. Ascospores acicular, tapered towards the distal end, side-by-side or loosely coiled in the ascus, (40–)42–*56.6*–70(–72) × 3–*3.5*–4(–4.5) µm (n = 40), with 12–17 septa distinct in water. Chemistry: no substances detected (plate 1A).

Critically, this species lacks any greenish, N+ crimson-red pigments, a feature that separates it from the otherwise similar *B. wellingtonii* (Stirt.) D.J.Galloway. In Tasmania, *B. laurocerasi* appears to be associated with lowland, often swampy *Melaleuca ericifolia*-dominated vegetation. In Australia, it has been recorded with certainty from Kangaroo Island (Kantvilas 2019), but other records remain unconfirmed.

TASMANIA: Moores Hill near Beaconsfield, 41°14'S 146°52'E, 80 m alt., 27 Apr. 1981, G. Kantvilas 256/81A (HO); Tatlows Beach Coastal Reserve, 40°47'S 145°17'E, 1 m alt., 15 May 2019, G. Kantvilas 154/19 (HO); Cape Portland, Musselroe Wind Farm, between Petal Point Road and Tregaron Lagoons, 40°47'S 147°58'E, 10 m alt., 9 Nov. 2018, G. Kantvilas 343/18 (HO).

Buellia extenuatella Elix & Kantvilas

This species is superficially similar to *Amandinaea conranensis* and *A. punctata* in having a highly reduced thallus and black apothecia, but is distinguished by the combination of a scurfy, membranaceous or sorediate upper surface, *Buellia*-type ascospores, 11–19 × 5–8 µm, and bacilliform conidia, (3–)4–6 × 0.5–1 µm. The Tasmanian specimen was epiphytic in *Allocasuarina*-dominated woodland, a habitat consistent with its occurrence on the southern Australian mainland (Elix & Kantvilas 2013).

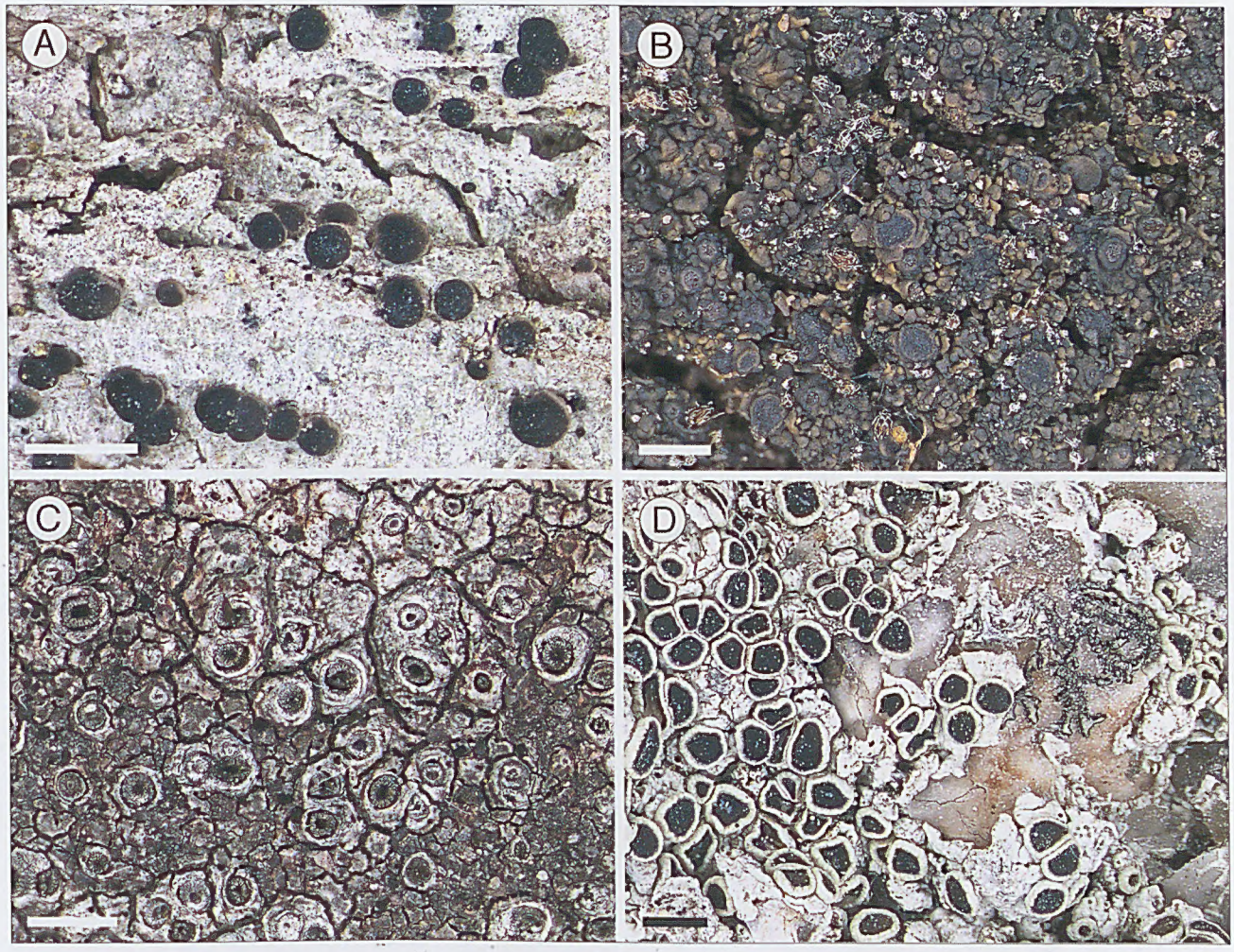

PLATE 1 – (**A**) *Bacidia laurocerasi*, with apothecia with a dark disc and a somewhat paler margin. (**B**) *Collema crispum*, showing the dark squamulose thallus with small, dark coloured apothecia. (**C**) *Diploschistes gyrophoricus*, with perithecioid ascomata. (**D**) *Lecanora pseudogangaleoides* subsp. *pseudogangaleoides*. Scales = 1 mm.

TASMANIA: Cape Portland, Musselroe Wind Farm: "Cadaver Ridge", 40°48'28"S 148°04'05"E, 65 m alt., 11 Sep. 2019, G. Kantvilas 225/19 (HO).

Catinaria atropurpurea (Schaer.) Vězda & Poelt

Characterised by a thin, undelimited crustose thallus, the typically reddish brown to blackish brown, biatorine apothecia, 0.2–0.8 mm wide, the 8-spored, *Catillaria*-type asci where the well-developed tholus is uniformly amyloid and lacks internal differentiation, the slender, paraphyses with reddish brown, swollen apices, and the hyaline, ellipsoid, 1-septate ascospores, 10–17 × 5–7.5 µm, with a gelatinous perispore *c.* 1 µm thick. Ascus structure distinguishes this species readily from several superficially similar genera, especially *Megalaria*, which also has 1-septate ascospores. *Catinaria atropurpurea* is widespread in temperate regions throughout the world. In Tasmania, it occurs on the bark of various trees and shrubs, mainly in coastal vegetation, but has rarely also been recorded inland in wet forest.

TASMANIA: Flinders Island, Yellow Beaches, 40°13'S 148°15'E, 2 m alt., 8 Aug. 1978, J.S. Whinray 1231 *p.p.* (HO); Cape Deslacs, 42°59'S 147°33'E, 1 Jun. 1980, G. Kantvilas 231/80 (BM, HO); Swan Basin, 42°12'S 145°16'E, sea-level, 21 Jan. 2000, G. Kantvilas 33/00 (HO); southern slope of South Sister, 41°32'S 148°10'E, 640 m alt., 10 Nov. 2004, G. Kantvilas 377/04A (HO); Florentine Bridge, 42°30'S 146°27'E, 360 m alt., 2 Nov. 2005, G. Kantvilas 315/05 (HO); Little Musselroe River estuary, 40°46'S 148°03'E, 5 m alt., 6 Nov. 2018, G. Kantvilas 181/18 (HO); St Helens Point, 10 m alt., 2020, G. Kantvilas 99/20 (HO).

Collema crispum (Huds.) Weber ex F.H.Wigg.

Characterised by a thallus of minute, squamiform lobes and lobules mostly up to *c.* 0.2 mm wide, and conspicuous apothecia to 1 mm wide, with a red-brown to black-brown, plane disc, a proper exciple of elongate (rather than paraplectenchymatous) hyphae, and 3-septate ascospores, 22–34 × 10–16 µm, occasionally with an additional longitudinal or oblique septum (plate 1B). In Tasmania, this species has been recorded on man-made substrata

(for example, the mortar of a ruined building) as well as on calcarenite in coastal heathland, and it has a similar distribution and ecology in other parts of the world (Gilbert *et al.* 2009). In his monumental work, Degelius (1974) did not formally record *C. crispum* from Tasmania, although he noted the existence of sterile specimens which might be this species. One such annotated specimen (G.C. Bratt 70/568, HO) was located but is considered here to be *Collema subflaccidum* Degel.

TASMANIA: Flinders Island, Trousers Point, 40°13'S 148°02'E, 10 m alt., 23 Mar. 2014, G. Kantvilas 368/14 (BG, HO); Cape Portland, Musselroe Wind Farm, The Ruins, N end of Home Beach, 40°45'12"S 147°57'28"E, 10 m alt., 8 Nov. 2018, G. Kantvilas 299/18, 302/18 (HBG, HO).

Diploschistes euganeus (A.Massal.) J.Steiner

Diploschistes euganeus is one in a complex of morphologically similar species which grows on non-calcareous rocks and has perithecioid ascomata (Mangold *et al.* 2009). It is characterised best by lacking lichen substances, a feature that distinguishes it from *D. gyrophoricus* and *D. sticticus* (Körb) Müll.Arg. (with gyrophoric acid) and from *D. aeneus* (Müll.Arg.) Lumbsch and *D. actinostomus* (Pers.) Zahlbr. (both with lecanoric acid). This widespread species has a scattered Tasmanian distribution on exposed rocks in low rainfall areas and displays a similar ecology in other parts of temperate Australia.

TASMANIA: Glen Morey Saltpan, near Tunbridge, 42°09'S 147°29'E, 180 m alt., 8 Nov. 1984, A. Moscal 8802 (HO); Cape Portland, 40°45'S 147°57'E, 5 m alt., 8 Nov. 2018, G. Kantvilas 282/18 (HO).

Diploschistes gyrophoricus Lumbsch & Elix

Like the preceding species, *D. gyrophoricus* is one of a group of morphologically similar species with perithecioid ascomata (plate 1C). It is characterised by the presence of gyrophoric acid and is distinguished from the chemically identical *D. sticticus* by subtle differences in the size and shape of its muriform ascospores. In *D. gyrophoricus*, these are (18–)20–*23.3*–27(–30) × (11–)13.5–*15.5*–18(–20) µm, broadly ovate-ellipsoid with broadly rounded apices, and with a length/width ratio of 1.3–*1.5*–1.8 (Tasmanian specimens, $n = 55$). In contrast, the ascospores of *D. sticticus* are ellipsoid and relatively longer and narrower: (22–)24–*34.9*–40(–42) × (11–)12–*17.1*–20(–21) µm, with a length / width ratio of 1.7–*2.0*–2.4 (Tasmanian specimens, $n = 28$). *Diploschistes gyrophoricus* is widespread in Tasmania on exposed rocks in rough pasture and dry sclerophyll woodland. It is also known from southeastern mainland Australia, New Zealand and South America.

TASMANIA: Hunting Grounds, Dysart, 42°34'S 147°10'E, 400 m alt., 7 Aug. 1981, G. Kantvilas 473/81 & P.W. James (HO); Spiky Bridge, 42°11'S 148°04'E, 0 m alt., 2 Feb. 1984, G. Kantvilas 166/84 & P.W. James (HO); *c.* 1 km NW of Tinderbox, 43°03'S 147°19'E, 160 m alt., 23 Jul. 2015, G. Kantvilas 253/15 (HO); 'Wind Song' Property, Ronnies Spur, 42°21'14"S 147°55'01"E, 30 m alt., 25 Oct. 2017, G. Kantvilas 238/17 (HO); Cape Portland, Musselroe Wind Farm, woodland W of Xanthorrhoea Ridge, 40°47'53"S 148°01'08"E, 70 m alt., 6 Nov. 2018, G. Kantvilas 365/18 (HO).

Endocarpon crassisporum P.M.McCarthy & Filson

With its grey-brown to reddish brown squamae, *c.* 2–10 mm wide, this species is superficially similar to *E. simplicatum* (Nyl.) Nyl., the most common species of *Endocarpon* in Tasmania. It is characterised by its consistently 1-spored asci and large, brown, muriform ascospores, 80–130 × (30–) 40–60 µm (see McCarthy 2001). It was found on consolidated, dolerite-derived soil in a very degraded coastal tussock grassland with extensive patches of bare soil and pebbles, a habitat consistent with its ecology on the Australian mainland.

TASMANIA: Cape Portland, N of Semaphore Hill, 40°45'S 147°57'E, 10 m alt., 8 Nov. 2018, G. Kantvilas 252/18 (HO).

Gyalecta pellucida (Coppins & Malcolm) Baloch & Lücking

This taxon was initially described in the genus *Belonia* by Coppins and Malcolm (1998) on account of its crustose thallus with a *Trentepohlia* photobiont, its pale pink, perithecioid apothecia, 0.2–0.3 mm wide, that have a proper exciple of rounded cells, thin-walled asci with a non-amyloid tholus but a thin, faintly amyloid wall, and acicular ascospores, 60–80 × 2.2–3(–4) µm, with *c.* 35–45 transverse septa. The genus *Gyalecta* in the traditional sense differs chiefly by having apothecioid ascomata with a plane to strongly concave or urceolate disc, and ellipsoid to fusiform, transeptate or muriform ascospores. The close relationship between these two genera was established by DNA-sequence data (Baloch *et al.* 2010). *Gyalecta pellucida* is an extremely inconspicuous species, very rare in Tasmania where it has been recorded from blackwood (*Acacia melanoxylon*)- or paper-bark (*Melaleuca ericifolia*)-dominated coastal swamps; it is also known from New Zealand.

TASMANIA: Stanley Peninsula, *c.* 30 m E of Wells Road, 40°45'S 145°17'E, *c.* 50 m alt., 28 Feb. 1998, A. Gray *s.n.* (HO); Cape Portland, Musselroe Wind Farm, northern end of Musselroe Bay, 40°48'36"S 148°06'41"E, sea-level, 11 Sep. 2019, G. Kantvilas 239/19 (HO).

Lecanora pseudogangaleoides Lumbsch subsp. *pseudogangaleoides*

Characterised by a prominent, continuous, yellowish grey to greenish grey thallus containing atranorin, usnic acid and

psoromic acid, and apothecia 0.5–1.3 mm wide, with a red-brown to black-brown disc and with large crystals, insoluble in KOH, in the margin; see Lumbsch and Elix (2004) for a complete description (plate 1D). The presence of psoromic acid, which distinguishes it from the very similar *L. wilsonii* Müll.Arg., can usually be detected by the P+ yellow reaction of the thallus. In Tasmania, this lichen is known only from outcrops of granite or quartzite in coastal heathland and dry sclerophyll woodland. It is also recorded from southeastern mainland Australia.

TASMANIA: The Gnomon, 41°11'S 146°02'E, 475 m alt., 25 May 1991, G. Kantvilas 236/91 (HO); unnamed hill *c.* 1 km NE of Coles Bay township, 42°07'S 148°17'E, 100 m alt., 23 Apr. 2007, G. Kantvilas 170/07 (HO); Cape Portland, Musselroe Wind Farm, "The Prairie", in the vicinity of Turbine D14, 40°48'35"S 148°06'23"E, 20 m alt., 11 Sep. 2019, G. Kantvilas 248/19, 251/19 (CANB, HO).

Lecanora strobilina (Spreng.) Kieff.

Lecanora strobilina is a member of the *L. symmicta* group, and the latter name has been broadly applied in Australia to specimens that contain atranorin and zeorin and have yellowish to brownish biatorine apothecia. As noted in several studies of Australian specimens (e.g. Lumbsch & Elix 2004, Kantvilas & LaGreca 2008, Pérez-Ortega & Kantvilas 2018), the group is complex and individual taxa can be difficult to distinguish. Even so, several species of the *L. symmicta* group are recognised in Tasmania, namely *L. helmutii* Pérez-Ortega & Kantvilas, *L. subtecta* (Stirt.) Kantvilas & LaGreca and *L. coppinsiarum* Kantvilas, as well as *L. symmicta* (Ach.) Ach. itself. Similar problems of species delimitation occur in the Northern Hemisphere (LaGreca & Lumbsch 2013), where *L. strobilina* is distinguished essentially by having apothecia with a persistent, crenulate thalline margin (plate 2A).

The *Lecanora symmicta* group was well-represented in the Musselroe Bay survey and included: *L. subtecta*, distinguished by having bright yellow, often pruinose, biatorine apothecia; *L. symmicta*, with pale yellow,

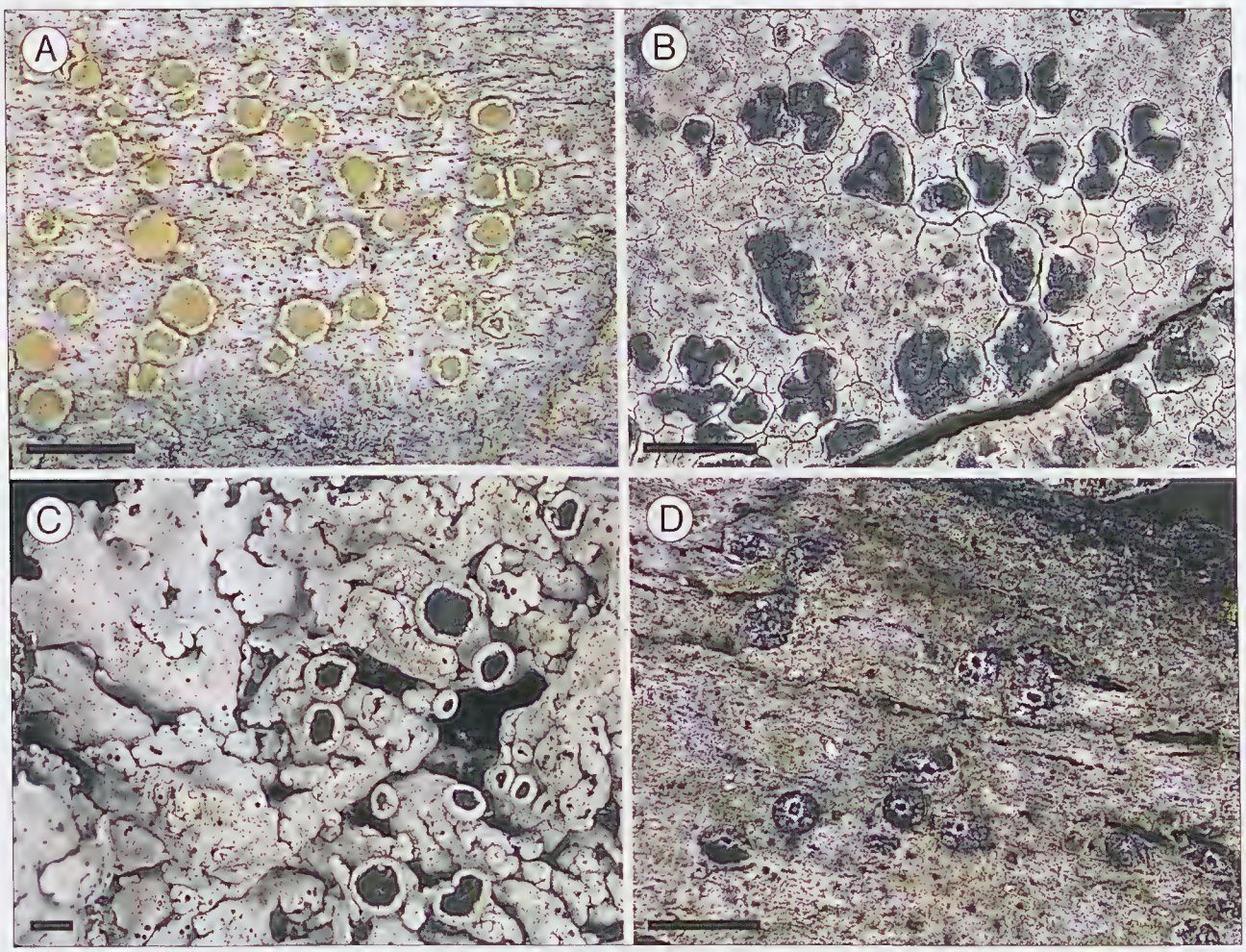

PLATE 2 – (**A**) *Lecanora strobilina*; note the apothecia with a persistent, crenulate, thalline margin. (**B**) *Opegrapha spodopolia*, with irregular, lirelliform apothecia with a central slit. (**C**) *Physcia austrostellaris*. (**D**) *Ramonia absconsa*, with tiny, semi-immersed apothecia with a central apical pore. Scales = 1 mm.

epruinose, biatorine apothecia; and a third entity with persistently lecanorine apothecia with a prominent crenulate margin. The name *L. strobilina* is applied to this last taxon, pending a more detailed review of the entire group. This lichen was observed frequently on bleached, split-eucalypt fenceposts and droppers in paddocks, as well as in patches of native vegetation where it grew on dead, standing wood.

TASMANIA: Cape Portland, Musselroe Wind Farm: vicinity of Turbine D8, 40°47'38"S 148°05'24"E, 30 m alt., 10 Sep. 2019, G. Kantvilas 252/19 (HO, MA); northern end of Musselroe Bay, 40°48'36"S 148°06'41"E, sea-level, 11 Sep. 2019, G. Kantvilas 232/19 (HO, MA); "Cadaver Ridge", 40°48'28"S 148°04'05"E, 65 m alt., 11 Sep. 2019, G. Kantvilas 224/19 (HO).

Opegrapha niveoatra (Borrer) J.R.Laundon

Characterised by simple, straight or curved lirellae, 0.4–1 mm long, with a black, K+ olive exciple (in section), and (3–)7-septate, acicular ascospores, 22–40 × 3.5–4 µm, with all cells ± equal in size (Pentecost & James 2009, Kantvilas 2019). In Tasmania, this ± cosmopolitan species has been collected mainly on *Melaleuca ericifolia* and appears to have a widely scattered distribution in the State.

TASMANIA: Passage Island, Bass Strait, 40°31'S 148°19'E, 11 m alt., 11 Oct. 1979, J.S. Whinray 1331 (MEL); Moores Hill, near Beaconsfield, 41°14'S 146°52'E, 80 m alt., 27 Apr. 1981, G. Kantvilas 253/81 (HO); Westwood Road, 41°29'S 146°59'E, 150 m alt., 21 Sep 2005, A.M. Buchanan 16307b (HO); Cape Portland, Musselroe Wind Farm, Tregaron Lagoons, "Copperhead Road", 40°46'46"S 147°57'58"E, 2 m alt., 9 Nov. 2018, G. Kantvilas 324/18 (HO).

Opegrapha spodopolia Nyl.

This species is characterised by the following salient characters: thallus pale grey, cream-grey or fawn brown, occasionally somewhat scurfy; ascomata lirelliform, black, mostly 0.3–0.6 mm long and up to 0.4(–0.6) wide, mostly elongate but sometimes approximately as long as wide; exciple usually highly convoluted, contorted and sulcate, closed or gaping at the apex, invariably open at the base, in section K+ olive-greenish; hymenium inspersed with oil droplets, with a brown, K+ pale olive epihymenial layer; ascospores (4–)5–6(–7)-septate, 20–26(–30) × 4–6 µm, with a gelatinous perispore that swells in KOH and becomes roughened with age; conidia rod-shaped, 4–6 × 0.5–1 µm (plate 2B). Originally described from New Zealand, this species was recently recorded from Kangaroo Island, South Australia (Kantvilas 2019). It is widespread along the coastlines of Tasmania, occurring on a wide variety of rock types including dolerite, quartzite, granite, serpentinite and mudstone. It grows in the rocky littoral zone in shaded sheltered overhangs. The genus *Opegrapha* is still poorly known in Tasmania. Many herbarium collections of saxicolous and corticolous species are yet to be identified, not least from coastal rocks. Features that best distinguish *O. spodopolia* are the basally open exciple and the dimensions and septation of the ascospores.

TASMANIA: Sleepy Bay, 42°08'S 148°19'E, sea-level, 2 Feb. 1984, G. Kantvilas 143/84 & P. James (BM, HO); Hibbs Pyramid, 42°36'S 145°16'E, 4 Feb. 1984, A. Moscal 6128c (HO); Doctors Rocks, 41°01'S 145°47'E, sea-level, 19 Feb. 1984, G. Kantvilas 391/84 & P. James (BM, H, HO); Lousy Gully, Curio Bay, 43°11'S 147°43'E, sea-level, 4 Feb. 2001, G. Kantvilas 154/01 (HO); Maingon Blowhole, 43°12'S 147°51'E, 40 m alt., 14 Oct. 2006, G. Kantvilas 359/06 (HO); Lion Rock, 43°36'S 146°49'E, sea-level, 27 Dec. 2007, G. Kantvilas 435/07 (HO); Mars Bluff, Bruny Island, 43°15'S 147°24'E, 5 m alt., 15 Mar. 2008, G. Kantvilas 40/08; Lion Rock, 43°36'S 146°49'E, 1 m alt., 21 Apr. 2013, G. Kantvilas 34/13 (HO); mouth of Interview River, 41°35'S 144°53'E, 3 m alt., 31 Jan 2015, G. Kantvilas 142/15 (HO); Goat Island, 41°08'S 146°08'E, 5 m alt., 24 Oct. 2016, G. Kantvilas 388/16 (HO); Cape Portland, Musselroe Wind Farm, shoreline near the Stone House, 40°45'S 148°01'E, 2 m alt., 9 Nov. 2018, G. Kantvilas 151/18 (HO); Cape Portland, 40°44'40"S 147°56'29"E, 2 m alt., 8 Nov. 2018, G. Kantvilas 261/18 (HO); northern end of Godfreys Beach, Stanley, 40°45'S 145°18'E, 1 m alt., 13 May 2019, G. Kantvilas 170/19 (HO).

Opegrapha varia Pers.

Characterised by relatively short lirellae with a K± brown exciple, and the fusiform, 4–6-septate ascospores, 18–38 × 6–8 µm, in which the central cell is noticeably enlarged. In Tasmania, this species has a scattered, coastal distribution and grows on wood or bark. It has been widely recorded throughout the world, including from mainland Australia. A detailed description is offered by Pentecost and James (2009).

TASMANIA: Flinders Island, Cave Beach, 40°01'S 147°53'E, 5 m alt., 23 Jan. 2006, G. Kantvilas 84/06 (HO); Bonnet Island, Macquarie Harbour, 42°13'S 145°13'E, 1 m alt., 14 May 2013, G. Kantvilas 144/13 (HO); Flinders Island, The Dock, 39°48'S 147°52'E, 10 m alt., 21 Mar. 2014, G. Kantvilas 298/14 (HO); Cape Portland, Musselroe Bay Conservation Area, Abalone Rocks, 40°47'26"S 148°06'08"E, 3 m alt., 7 Nov. 2018, G. Kantvilas 388/18 (HO)

Physcia austrostellaris Elix

Characterised by an essentially orbicular thallus, with radiating, ± rounded, esorediate lobes to *c.* 2 mm wide at the margins, a pale brown to ivory under-surface, apothecia to 2.5 mm wide, with a brown-black disc that is often thickly greyish pruinose, and by the presence of the triterpene, 20α-acetoxyhopane-6α,22-diol, in addition to atranorin (plate 2C). Although found occasionally in dry sclerophyll vegetation, where it occurs on the bark of understorey trees

such as *Allocasuarina*, or on wood or rocks, this species is most commonly seen on exotic trees in parks and along roadsides. The Musselroe Bay specimen was collected from dolerite boulders in an *Allocasuarina verticillata*-dominated woodland. In earlier literature pertaining to Australian lichens, this species was referred to as *P. stellaris* (L.) Nyl., a name now applied strictly to a superficially similar Northern Hemisphere species that differs by having narrower lobes, often with secondary lobules in the centre of the thallus, numerous, simple or branched, whitish to dark brown or grey rhizines that often protrude beyond the lobe margins and lacks any triterpenes additional to atranorin (Elix *et al.* 2009).

TASMANIA: Poatina, 41°48'S 146°58'E, 900 m alt., Jan. 1964, G.C. Bratt 1315 (HO); Lake Tooms Road, 42°03'S 147°30'E, 19 Dec. 1974, G.C. Bratt 74/1245 & M. Gilbert (HO); Reeves Creek, Picnic Rocks, 40°59'S 148°19'E, 20 m alt., 13 Sep. 1983, A. Moscal 2668 (HO); Red Rocks, 41°00'S 148°19'E, 20 m alt., 19 Oct. 1983, A. Moscal 3646 (HO); Campbell Town, 41°56'S 147°29'E, 14 Feb. 1984, G. Kantvilas 454/84 & P. James (BM, HO); Don Heads, 41°10'S 146°20'E, 3 m alt., 27 May 1990, G. Kantvilas 282/90 (HO); 2 km W of New Norfolk, Glenora Road, 42°47'S 147°02'E, 90 m alt., 19 Feb. 1997, G. Kantvilas 72/97 (HO); St Helens, 41°19'S 148°14'E, 10 m alt., 20 Feb. 2001, G. Kantvilas 270/01 (HO); Evandale, edge of Rodgers Lane, 41°34'S 147°15'E, 160 m alt., 21 Mar. 2001, J. Jarman *s.n.* (HO); Glen Esk Road near Middle Run Hill, 41°48'S 147°27'E, 220 m alt., 24 Aug. 2001, G. Kantvilas 755/01 (HO); Windmill Hill, Launceston, 41°26'S 147°09'E, 18 Jul. 2001, J. Jarman *s.n.* (HO); Auburn Road, 42°00'S 147°19'E, 230 m alt., 12 Dec. 2001, G. Kantvilas 1297/01 (HO); Mole Creek, 41°34'S 146°24'E, 240 m alt., 2 Mar 2002, G. Kantvilas 141/02 (HO); Cape Portland, Musselroe Wind Farm, woodland W of Xanthorrhoea Ridge, 40°47'53"S 148°01'08"E, 70 m alt., 6 Nov. 2018, G. Kantvilas 357/18 (HO).

Ramonia absconsa (Tuck.) Vězda

This species is characterised by the following salient features: thallus crustose, effuse, very thin and patchy, pale grey-green, with a *Trentepohlia* photobiont; apothecia 0.3–0.5 mm wide, at first immersed or semi-immersed and visible as a 'bump' in the thallus, pierced by a minute central pore with a grey rim, emergent when mature, becoming globose to hemispherical, with a dark brown, strongly incurved, radially split proper exciple, and a central pore to *c.* 0.15 mm wide, revealing a pale grey, urceolate disc; exciple in section cupulate, hyaline to brown, composed of rhomboidal or subglobose, parenchymatous cells 3–7 µm wide and lined along the inner edge with periphyses 5–10 × 2–3 µm; asci 32-spored, of the *Gyalecta*-type, with a thin, KI+ blue wall and non-amyloid, poorly developed tholus; ascospores (12)13–19(–20) × 5–6.5(–7) µm, 3(–5)-septate, ellipsoid, blunt or acute at the apices, with a gelatinous perispore (plate 2D).

This is a remarkable discovery for Tasmania, based on a single collection from the papery bark of an old *Melaleuca ericifolia* in a lowland, coastal swamp. Prior to this collection, it was known only from the type specimen, collected in the nineteenth century from the bark of maple in South Carolina, U.S.A. (Vězda 1966, 1967).

TASMANIA: Cape Portland, Musselroe Wind Farm, Tregaron Lagoons, 40°46'55"S 147°58'09"E, 2 m alt., 2019, *G. Kantvilas* 230/19 (E, HO).

Trapelia concentrica Elix & P.M.McCarthy

Recently described from New South Wales and the A.C.T. by Elix and McCarthy (2019), this species is characterised by a thallus of minute, highly dispersed, scabrid areoles to 0.3 mm wide, scattered apothecia to *c.* 0.5 mm wide, and ascospores 11–17 × 6–10 µm. Elix and McCarthy (2019) compare it to *T. crystallifera* Kantvilas and Elix, which in Tasmania occurs exclusively on soil. However, the single Tasmanian specimen of *T. concentrica* is from rock, and is therefore more likely to be confused with the common, widespread and highly variable *T. coarctata* (Sm.) M.Choisy. It grew on dolerite pebbles in a highly degraded tussock grassland.

TASMANIA: Cape Portland, N of Semaphore Hill, 40°45'S 147°57'E, 10 m alt., 8 Nov. 2018, G. Kantvilas 253/18B (HO).

The genus *Trapelia* in Tasmania is complex and requires considerable further study. An additional, as yet unidentified species was also collected at the study site (Kantvilas 226/19; HO). It grew on consolidated soil and had scattered, sorediate squamules containing gyrophoric acid, and ascospores 24–31 × 12–17 µm.

Xanthoparmelia xerica (Elix) Elix

Characterised by an almost subcrustose, grey or blackened thallus of minute, tightly adnate lobes, mostly only to 0.1 mm wide, which become rather spidery at the thallus margins, with a pale brown underside, sparse, globose isidia and containing atranorin and stictic acid. Previously known only from the type locality on the Eyre Peninsula, South Australia, this rare lichen was collected in Tasmania on a granite boulder in coastal scrubby heathland. It could potentially be confused with the very common and widespread *X. mougeotina* and *X. xanthomelaena* with which it grows, both of which contain stictic acid but differ by also containing usnic acid instead of atranorin, and have a black under-side; the latter differs further in lacking isidia.

TASMANIA: Cape Portland, Musselroe Wind Farm, "The Prairie", in the vicinity of Turbine D14, 40°48'35"S 148°06'23"E, 20 m alt., 5 Nov. 2018, G. Kantvilas 210/18 (HO).

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REFERENCES

Baker, M., Grove, S., de Salas, M., Byrne, C., Cave, L., Bonham, K., Moore, K. & Kantvilas G. 2019: Tasmanian Museum and Art Gallery's Expedition of Discovery 1 – The flora and fauna of *Wind Song*, Little Swanport, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **153:** 5-30.

Baloch, E., Lücking, R., Lumbsch. H.T. & Wedin, M. 2010: Major clades and phylogenetic relationships between lichenized and non-lichenized lineages in Ostropales (Ascomycota: Lecanoromycetes). *Taxon* **59:** 1483–1494.

Coppins, B.J. & Malcolm, W.M. 1998: A new *Belonia* from New Zealand and a second record of *B. mediterranea*. *Lichenologist* **30:** 563–566.

Degelius, G. 1974: The lichen genus *Collema* with special reference to the extra-European species. *Symbolae Botanicae Upsalienses* **20**(2): 1–215.

Ekman, S. 1996: The corticolous and lignicolous species of *Bacidia* and *Bacidina* in North America. *Opera Botanica* **127:** 1–148.

Elix, J.A. 2014: *A Catalogue of Standardized Chromatographic Data and Biosynthetic Relationships for Lichen Substances*. Third Edition. Canberra: published by the author.

Elix, J.A. & Kantvilas, G. 2013: New taxa and new records of *Buellia sensu lato* (Physciaceae, Ascomycota) in Australia. *Australasian Lichenology* **73:** 24–44.

Elix, J.A. & McCarthy, P.M. 2019: *Trapelia concentrica* (lichenized Ascomycota, Trapeliaceae), a new species from south-eastern Australia, with a key to the genus in Australia. *Australasian Lichenology* **85:** 46–50.

Elix, J.A., Corush, J. & Lumbsch, H.T. 2009: Triterpene chemosyndromes and subtle morphological characters characterise lineages in the *Physcia aipolia* group in Australia (Ascomycota). *Systematics and Biodiversity* **7:** 479–487.

Elix, J.A., Kantvilas, G. & McCarthy, P.M. 2017: Thirteen new species and a key to buellioid lichens (Caliciaceae, Ascomycota) in Australia. *Australasian Lichenology* **81:** 26–67.

Elix, J.A., Kantvilas, G. & McCarthy, P.M. 2019a: Two new species of *Rinodina* (Physciaceae, Ascomycota) from southern Australia. *Australasian Lichenology* **84:** 10–15.

Elix, J.A., Kantvilas, G., McCarthy, P.M. & Archer, A.W. 2019b: Additional lichen records from Australia. *Australasian Lichenology* **84:** 55–71.

Gilbert, O.L., James, P.W. & Purvis, O.W. 2009: Collema F.H.Wigg. (1780). *In* Smith, C.W., Aptroot, A., Coppins, B.J., Fletcher, A., Gilbert, O.L., James, P.W. & Wolseley, P.A. (eds): *The Lichens of Great Britain and Ireland*, London, British Lichen Society: 345–357.

Hafellner, J. 1984: Studien in Richtung einer natürlicheren Gliederung der Sammelfamilien Lecanoraceae und Lecideaceae. *Beiheft zur Nova Hedwigia* **79:** 241–371.

Jarman, S.J. & Kantvilas, G. 1994: Lichens and bryophytes of the Tasmanian World Heritage Area. II. Three forest sites at Pelion Plains. *Tasforests* **6:** 103–120.

Jarman, S.J. & Kantvilas, G. 1995: *A floristic study of rainforest bryophytes and lichens in Tasmania's myrtle-beech alliance*. Tasmanian NRCP Report No. 14. Forestry Tasmania and Department of Environment, Sport & Territories, Canberra.

Kantvilas, G. 1989: A checklist of Tasmanian lichens. *Papers and Proceedings of the Royal Society of Tasmania* **123:** 67–85.

Kantvilas, G. 1994: A revised checklist of the Tasmanian lichen flora. *Muelleria* **8:** 155–175.

Kantvilas, G. 2012: The genus *Menegazzia* (Lecanorales: Parmeliaceae) in Tasmania revisited. *Lichenologist* **44:** 189–246.

Kantvilas, G. 2019: An annotated catalogue of the lichens of Kangaroo Island, South Australia. *Swainsona* **32:** 1–97.

Kantvilas, G. & Coppins, B.J. 2019: Studies on *Micarea* in Australasia II. A synopsis of the genus in Tasmania, with the description of ten new species. *Lichenologist* **51:** 431–481.

Kantvilas, G. & Jarman, S.J. 2012: Lichens and bryophytes in Tasmanian wet eucalypt forest: floristics, conservation and ecology. *Phytotaxa* **59:** 1–31.

Kantvilas, G. & LaGreca, S. 2008: *Lecanora subtecta*, an Australian species in the *Lecanora symmicta* group. *Muelleria* **26:** 72–76.

Kantvilas, G., Jarman, S.J. & McCaffrey, N. 2012: A contribution to the flora of the Meredith Range, north-western Tasmania. *Kanunnah* **5:** 127–140.

LaGreca, S. & Lumbsch. H.T. 2013: Taxonomic investigations of *Lecanora strobilina* and *L. symmicta* (Lecanoraceae, Lecanorales) in northeastern North America. *The Bryologist* **116:** 287–295.

Lumbsch, H.T. & Elix, J.A. 2004: *Lecanora*. *Flora of Australia* **56A:** 12–62.

Mangold, A., Elix, J.A. & Lumbsch, H.T. 2009: Thelotremataceae. *Flora of Australia* **57:** 195–420.

McCarthy, P.M. 2001: *Endocarpon*. *Flora of Australia* **58A:** 161–167.

McCarthy, P.M. 2020: *Checklist of the Lichens of Australia and its Island Territories*. Australian Biological Resources Study, Canberra. Version 1, March 2020. http://www.anbg.gov.au/abrs/lichenlist/introduction.html.

McCarthy, P.M. & Kantvilas, G. 2018: *Anisomeridium disjunctum* (Monoblastiaceae), a new lichen species from Tasmania, with a key to the genus in Australia. *Australasian Lichenology* **83:** 54–60.

Pentecost, A. & James, P.W. 2009: Opegrapha Ach. (1809). *In* Smith, C.W., Aptroot, A., Coppins, B.J., Fletcher, A., Gilbert, O.L., James, P.W. & Wolseley, P.A. (eds): *The Lichens of Great Britain and Ireland*, London, British Lichen Society: 631–647.

Pérez-Ortega, S. & Kantvilas, G. 2018: *Lecanora helmutii*, a new species from the *Lecanora symmicta* group from Tasmania. *Herzogia* **31 (1) Teil 2:** 639–649.

Vězda, A. 1966: Flechtensystematische Studien III. Die Gattungen *Ramonia* Stiz. und *Gloeolecta* Lett. *Folia Geobotanica et Phytotaxonomica Praha* **1:** 154–175.

Vězda, A. 1967: Flechtensystematische Studien V. Die Gattung *Ramonia* Stiz. Zusätze. *Folia Geobotanica et Phytotaxonomica Praha* **2:** 311–317.

Wetmore, C.M. 1963: Catalogue of the lichens of Tasmania. *Revue Cryptogamie Bryologique et Lichénologique* **32:** 223–264.

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POTENTIAL POLLEN VECTORS OF THE MASS FLOWERING TREE *ACACIA DEALBATA*, WITHIN ITS NATURAL RANGE IN SOUTHERN TASMANIA

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(with three figures, three plates, six tables and two appendices)

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In Tasmania, *Acacia dealbata* flowers from July to September when weather conditions are non-conducive to activity by the insects which are generally considered to be major pollinators of the genus. This paper examines the presence and behaviour of insect and bird visitors as potential pollen vectors. Very few insects were observed to visit the flowers. However, several bird species fed on the flower-heads and foraged for small invertebrates inhabiting the blossoms. These feeding behaviours resulted in adhesion of pollen to feathers likely to be transferred from one genet to another as birds moved. During feeding, rosellas were observed to not only ingest flower-heads but the presence of branchlet clip under 57% of *A. dealbata* trees surveyed is evidence of the widespread occurrence of these species foraging on flowers. However, given the profusion of flowers and the small numbers of birds observed, it is difficult to conclude that birds are wholly responsible for outcross pollination and we discuss the possibility that wind may also be an important pollen vector. Although the floral attributes of *A. dealbata* are more aligned with insect pollination, we failed to definitively identify any one major pollinator of the species in this environment and suggest that the pollination syndrome may most accurately be described as generalist.

Key Words: *Acacia dealbata*, pollination syndrome, bird pollination, insect pollination, wind pollination, mass flowering.

INTRODUCTION

Silver Wattle (*Acacia dealbata*) is native to southeastern Australia with a range extending from Tasmania and western Victoria to northern New South Wales. It is common in forest and woodland communities in Tasmania from sea level to 900 m, and dominates many transitional forests on disturbed sites (Kitchener & Harris 2013), varying in size from a low shrub on dry sites to a tall tree over 25 m in height on deep soils in wetter sites (Boland *et al.* 2006). The species has also been widely planted outside Australia for ornamental purposes, perfumery and fuelwood (Griffin *et al.* 2011) and has a reputation for weediness via both seed and root suckering (Gibson *et al.* 2011, Fuentes-Ramirez *et al.* 2011, Montesinos *et al.* 2016). Because of the tendency to sucker (Nghiem *et al.* 2018), pollen transfer between trees is not always an outcrossing event and we use the term 'genet' to indicate trees of different genotype.

The species produces a spectacular display of bright yellow flowers from July to September, a time of year characterised by low temperatures with frequent strong winds and rain, not conducive to insect flight activity. However, substantial pollen transfer between genets is presumed to occur as Broadhurst *et al.* (2008) found that seed from elsewhere within the natural range was highly outcrossed. The vector(s) mediating such cross-pollination in Tasmanian populations are by no means obvious.

According to the pollination syndrome hypothesis, convergent evolution may lead to unrelated plants sharing the same suite of floral traits when they are pollinated by the same abiotic or functional group of biotic vectors (Faegri & van der Pijl 1979, Rosas-Guerrero *et al.* 2014). For biotic pollinators, floral traits include rewarding (e.g. nectar and pollen) and non-rewarding attractants (e.g. floral colour, shape and scent), while the wind-pollination syndrome is typically associated with an absence of attractants, the flowers being nectarless and lacking bright colours and scent (Faegri & van der Pijl 1979, Sedgley & Griffin 1989).

Acacia species are generally considered to be pollinated by insects, particularly bees (Bernhardt 1989, Stone *et al.* 2003), but the floral traits do not map tightly onto any of the major pollinator syndromes as defined by Faegri and van der Pijl (1979). In terms of gross morphology, the flowers are remarkably uniform, a characteristic feature being the prominence of anther filaments which generally determine the shape, size and (generally yellow) colour of the flower-heads, which may be globose to spicate (Kendrick 2003). The number of individual flowers per head and heads per inflorescence are variable and all may not be perfect. Pollen is aggregated into polyads containing 4<32 grains. The flowers do not produce nectar and while extra-floral nectaries are generally present (Boughton 1981), in many species, including *A.dealbata*, they are only vestigial (Marazzi *et al.* 2019) and offer no reward to visitors. Low reproductive success is also a characteristic of the genus with typically less than one pod produced per flower-head (Wandrag *et al.* 2015). Nevertheless, because of the large number of flowers per tree, individuals may produce several

thousand seeds/m^2/yr^{-1} (Gibson *et al.* 2011) which can remain viable in the soil for many decades.

Although birds are not considered to be major pollinators of *Acacia* (Ford *et al.* 1979), there are examples of birds feeding on or within flowering crowns of several species (Sargent 1928, Ford & Forde 1976, Knox *et al.* 1985, Vanstone & Paton 1988), raising the possibility of a role as pollen vectors. The possibility of wind pollination was not considered in earlier reviews of the pollination ecology of the genus (Bernhardt 1989, Stone *et al.* 2003) but there is sufficient evidence to suggest at least a contribution to gene flow. Polyads have been collected downwind of *A.mearnsii* trees (Moncur *et al.* 1991, Kendrick 2003); Smart and Knox (1979) found *Acacia* polyads in the atmosphere over Melbourne during spring; and allergy to airborne *Acacia* pollen has been reported from a number of countries (Ariano *et al.* 1991). A recent experimental study of *A. longifolia* in Portugal found that seed set was enhanced when flowers were exposed to wind (Giovanetti *et al.* 2018).

The effectiveness of any particular flower visitor as an outcrossing agent is a function of its morphology and behaviour (affecting the probability of collecting pollen during the course of feeding and of deposition on flowers of a different genet) and of population size relative to the number of flowers produced by the host plant population. Together these variables determine the potential flux of pollen between trees (Griffin *et al.* 2009). For effective pollination the pollen must obviously be viable when deposited, so it is important to understand the temporal decay in viability post-anthesis. As a contribution to understanding the pollination ecology of *A.dealbata*, this paper reports an observational study of the presence and behaviour of the diurnal visitors to the crowns of trees in natural populations near Hobart, Tasmania. It also considers the possibility of wind pollination and tentative conclusions are drawn regarding all the relative importance of the potential vectors in effecting outcrossing.

MATERIALS AND METHODS

Reproductive characteristics of *A. dealbata*

Flowers are arranged in globose heads which, when the filaments are fully expanded, measure about 9 mm wide by 8 mm long with a fresh weight of 20 mg (Griffin unpubl. data). The number of individual flowers per head varies between 22 and 42 (Roger & Johnson 2013, Correia *et al.* 2014) with varying numbers being male only. Each flower has an average of 33 stamens (Correia *et al.* 2014). Heads are arranged in axillary racemes or false panicles on branch apices which collectively form a highly visible mass blossom (pl. 1) and Figure 1 in Nghiem *et al.* (2018). Pollen is aggregated into 16 grain polyads which average 46 µm in diameter (Nghiem *et al.* 2018). The flowers do not produce nectar and the extra-floral nectaries are vestigial (Marazzi *et al.* 2019) and offer no reward. The low fruit:flower ratio

PLATE 1 — Flowering (26/8/18) and corresponding mature pod crop (1/1/19) on adjacent trees at Site 4. The bright yellow colour of Tree 4 (left) indicates it was in full flower, while Tree 5 (right) was past the peak. Both the flowers and resulting pod crops were distributed uniformly from the topmost branches to the lowest in the crown on each tree (photos J. Harbard).

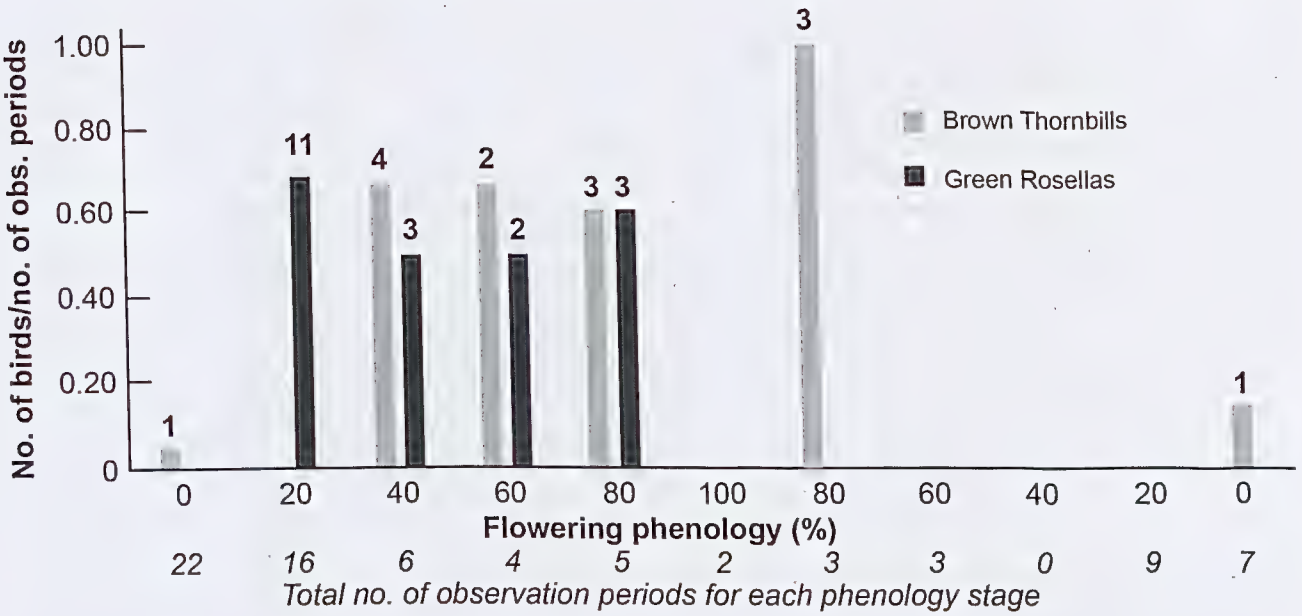

FIG. 1 — Ratios of total number of birds sighted on *A. dealbata* crowns to total number of observation periods at each flowering phenology stage, summed across the five observation points at Knocklofty, for Brown Thornbills and Green Rosellas. Numbers above each bar show the total number of birds sighted for each phenology stage. Flowering phenology scored as the proportion of flowers judged to be fully open on a scale of 0 (pre- and post-flowering) to 5 at peak flowering.

of the species aligns with the rest of the genus. In Portugal, Correia *et al.* (2014) reported fruit developed from only 0.7% of the total number of flowers observed. In South Africa, Rodger and Johnson (2013) reported that after open pollination 14% of *A. dealbata* flower-heads matured one or more fruit while, for a range of natural populations in NSW, infructescences per flower-head varied between 0.03<0.31 (Broadhurst & Young 2006, Wandrag *et al.* 2014).

Observation sites

The core study was conducted at the Knocklofty Reserve near Hobart (Site 1) but we also report data collected from a number of other sites within the region (table 1). All sites can broadly be regarded as part of a single ecosystem in the foothills of kunanyi/Mount Wellington to the west of Hobart, where *A. dealbata* is present as a result of regeneration following fire or other disturbance, although the density and age class structures differ, with likely effects on the pool of potential pollinations. All are within 15 km of Site 1 and between 50–300 m elevation (Site 1 is at 220 m).

Floral phenology

It is highly probable that the state of flower development within a tree crown affects desirability as a food source for visiting animals, so we characterised this for each observation date. In *A. dealbata* there is a gradual colour change associated with flower opening, from pale to brighter yellow and then paler again past the peak. Each time observations were made,

TABLE 1 – Observation sites

Site No.	Location	Latitude S	Longitude E	Elevation (m asl)	Distance from Site 1 (km)	Data collected
1	Knocklofty Reserve	42°53'07"	147°18'07"	220	–	Bird and invertebrate observation, mist netting
2	Mt Nelson	42°54'48"	147°19'23"	140	3.7	Bird observation
3	Lower Longley	42°58'20"	147°11'41"	200	14.5	Bird observation
4	Turnip Fields Rd	42°54'51"	147°16'20"	300	3.6	Wind dispersal, seed production
5	Waterworks Reserve	42°54'32"	147°16'12"	160	2.4	Mist netting birds
6	BOM Station 094029 Ellerslie Rd, Hobart	42°53'20"	147°19'34"	50	1.5	Meteorological data

the flowering state of each tree at each Observation Point (OP) was placed in one of 11 categories according to the percentage of heads which were fully open, from 0 < 100% (peak flowering) at 20 percentile intervals reducing from this peak date to 0%, again in 20 percentile steps, as the proportion of open heads declined over time. Individual trees thus moved through a progression from 0% to peak (100%) flowering and back to 0%. An average score was then calculated for all trees at each bird OP at each study site on each date. For the invertebrate study there was only one target tree at each OP and for results presentation we averaged values over the four trees observed on each visit date.

Meteorological data

A basic tenet of the study was that the pollination ecology of winter/spring flowering *A. dealbata* may differ from many other *Acacia* species which flower at warmer times of the year, so we documented the ambient weather conditions through the flowering period using data from the Australian Bureau of Meteorology Station 094029 at Ellerslie Rd, Hobart (table 1) for the study period June–Sept 2018 (Bureau of Meteorology 2018).

Invertebrates visiting or resident within the blossom

Four trees at Site 1 were chosen for study. The locality, described by Nghiem *et al.* (2018), is dry sclerophyll eucalypt woodland dominated by *Eucalyptus globulus* and *E. viminalis*, with an understorey of *A. dealbata* and other species, but is known to have been more open in the past, with a complex history of degradation and revegetation (Harwood *et al.* 2018). Each tree was flowering heavily at a height that was easily accessible from the ground. Observations were made on nine days between 30 June 2018 prior to flowering and 18 September, when flowering was completed. Observation days were chosen as being dry and without strong winds, since we expected insect activity to be low under less favourable conditions. For one 10-minute period per tree per observation day we recorded larger flying insects which could be potential pollen vectors. An observer stood close to a heavily flowering part of the crown and noted the number of each taxon which came into view. Where there was some doubt about identification, samples were collected for later examination or in some cases photographed *in situ*. Where possible, identification was made to the Family level but, with the exception of bees and Syrphid flies, which Bernhardt (1987) considered to be particularly important vectors of *Acacia* pollen, summary at the level of Order was considered sufficient to meet the study objectives.

We also sampled the small invertebrates living among the inflorescences which represent a potential food source for foraging birds. On each sample day four different flowering branches on each tree were sharply beaten with a 40-cm stick, at an approximate foliage height of 150 cm. A container held immediately below the branches collected the organisms which were dislodged. In order to minimise loss of flying insects the container was fitted with a flexible plastic cover which could be removed and replaced with minimum delay for each of the collections. The pooled contents were then inspected and numbers of each taxon counted. Since a few of the more vigorous flyers (mainly Diptera and Hymenoptera) did escape during the counting process there is some bias associated with the method. However, the more stationary invertebrates are presumed the more likely food for birds, so we do not consider this a critical issue. Where identification was difficult, a digital photographic image was taken for immediate inspection or in some cases later consultation of databases. The camera used was a Canon EOS6D, with Canon MPE65 mm macro lens and Macro twin lite MT-26EX-RT, permitting identifiable images of invertebrates greater than around 2 mm in length. In order to judge whether the invertebrate fauna was different on flowering and non-flowering trees, on four of the observation days we also beat the foliage of an entirely vegetative tree growing next to Tree 1. Our capacity to identify the various taxa increased from Species, Genus, Family to Order. For the purposes of this paper we were primarily interested in determining the diversity of organisms over the flowering season and presentation at the level of Order was considered sufficient. More detailed data to Family level are provided in appendix 1, where we also indicate the developmental stage observed, since some taxa were present in a range of immature states (as determined from morphology and/or size) as well as adult form.

Bird visitors

At Site 1, five fixed OPs were chosen within an area approximately 250 m by 150 m. Each OP gave an uninterrupted view of 1–5 mature *A. dealbata* trees from a viewing position next to a nearby tree or shrub that provided cover for the observers. Observations were made on 18 days during the period from 26 June (about 2 weeks prior to first anthesis) to 29 September 2018 by which time all flowering had finished. Data were collected by either one or two experienced bird observers with binoculars and cameras. Intervals between the observation days averaged 5.8 days but ranged from 3 to 10 days, depending on the availability of observers and weather conditions.

A second series of observations over the flowering season (26 July to 19 September 2018) was made by another observer at Site 2 (table 1). Ten OPs were selected, seven located within low dry sclerophyll forest with many flowering *A. dealbata* stems 2–8 m high originating from a past fire event and three in suburban settings near the forest but within 20 m of buildings that included 1–4 larger *A. dealbata* trees. The number of observations at each OP ranged from 17 to 31.

A third data set was collected at Site 3 (table 1). Observations were made on a total of ten days between 2 August to 12 October 2018 at a single OP adjacent to a row of five large roadside *A. dealbata* trees on a lightly wooded rural property surrounded by wet sclerophyll forest.

At all sites, observations commenced between 7.30 am to 3 pm, with the majority of observations made in the mornings. Periods of the day with very high winds

(terrestrial Beaufort scale ≥7, large trees in motion) and/or heavy all-day rain were excluded. Ambient temperatures at the time of observation were mostly within the range 10–15°C. A point count of ten minutes was made at each OP. During each count, all bird species visible from the OP, or identified from their nearby calls, were recorded. The numbers of birds of each species that alighted on the *A. dealbata* trees under observation, and the numbers that moved between *A. dealbata* trees, were recorded. At Sites 1 and 2 the behaviour of birds in *A. dealbata* tree crowns was noted and each visit recorded as either feeding on inflorescences; contacting flowers; or perching. The frequency of visits by birds that foraged on or among inflorescences of *A. dealbata* in relationship to flowering phenology stages was examined by calculating the proportions of visits to observation periods for each phenological stage.

Indirect evidence of rosella feeding

It was noted that where Green Rosellas (*Platycercus caledonicus*) had been feeding on *A. dealbata* flower-heads, the ground under the tree was often littered with freshly clipped flower-bearing branchlets, each severed with a characteristic clean diagonal cut (pl. 2). This provided an indirect measure of activity. To estimate the proportion of trees where this type of feeding had occurred, we inspected the ground under *A. dealbata* trees at nine regional locations where many trees were in heavy flower and there was relatively little undergrowth. Surveyed trees were classified as either plus or minus evidence of rosella feeding (three or more clipped branchlets found under the crown were classified as plus). Results were expressed as percentage of trees with evidence of rosella feeding. It was not possible to judge the time the material had been on the ground and when the feeding had occurred, so we cannot say whether one or more feeding events were involved.

Pollen carried by birds

For a bird to be an effective outcross pollen vector there must be transfer of polyads from anthers to the bird during the course of a feeding event and from thence to stigmas on another genet. To obtain relevant data we mist-netted bush birds from 7:00 to 11:00 am at Sites 1 and 5 (table 1) while the *A. dealbata* were flowering. Site 5 was first sampled on 22 July, early in the flowering season, with many more trees flowering during the subsequent visit one month later. At Site 1 nets were set near two of the four bird OPs on three occasions at approximately weekly intervals around the peak flowering season in August.

To obtain a pollen swab, doubled-sided tape was applied to a glass microscope slide and, while the bird was still in the mist net (that is before pollen could be rubbed or shaken off), the slide was applied sequentially to the head, beak, feet and chest feathers. Slides were observed through a compound microscope at 400× magnification, viewing transects across the slide until the whole slide had been observed. Total number of polyads was recorded and classified to at least the Family level.

PLATE 2 — Green Rosella feeding on flower-heads from a clipped branchlet of *A. dealbata* (photo M. Brown).

Pollen viability on feathers

It was not possible to directly determine viability of pollen carried by birds so we conducted a simulated trial. An equal number of flower-heads was harvested from each of four trees at Site 4 and mixed prior to pollen extraction. Since anthers were closed, the flower-heads were left under lights for 30 minutes causing dehiscence and exposure of the polyads. Flowers were then placed in an Endecotts test sieve with a 63 µm stainless steel mesh over a petri dish containing clean feathers from a mist-netted Crescent Honeyeater (*Phylidonyris pyrrhopterus).* Gentle rubbing separated the polyads from the anthers which settled on the feathers. These were left in a petri dish in an unheated room (temperature range 6–11°C) which was within the range of outside air temperatures over the observation period (Bureau of Meteorology 2018). At intervals between 0 and 17 days, a sample of polyads was collected by gently scraping a dissecting needle over the feathers onto a petri dish containing 1% agar, 20% sucrose and 0.01% boric acid kept at the same ambient temperature. Preliminary experiments determined that maximum germination of fresh polyads was achieved after 48 h so this was set as the test period. Viability was assessed by viewing pollen tube growth on the nutrient agar at 160× magnification with an inverted Nikon microscope; 100 polyads were observed on each occasion. A polyad was counted as viable if one or more pollen tubes had germinated and the length was greater than the diameter of the polyad. On Day 3, as germination rate had obviously slowed, the dish was inspected again at 72 h. From Day 7, in order to achieve maximum germination, petri dishes were transferred to a growth room at a higher temperature (15–23°C).

Wind dispersion of flower-heads

From casual observation it was evident that whole flower-heads detached rather easily in windy conditions and were frequently seen on the ground among the trees. It is possible to extract viable pollen from such heads (J. Harbard unpubl. data 2018) so this may be regarded as a possible pollen dispersal mechanism. Following a particularly windy week we documented the dispersal of heads away from a forest margin at Site 4. Three parallel transects were laid out across grassland and all heads within a 0.75 m^2 wooden frame were counted at 1.5 m intervals out from below the edge of the canopy to a distance of 50 m. Counts were then converted to a per 1 m^2 basis and plotted against distance.

Pod and seed production

In parallel with this study we have also made a detailed investigation of the floral biology and seed production of this *Acacia* species. Full details will to be reported elsewhere, but we present some information which, in conjunction with the observed activity of potential pollen vectors, assists inference regarding the overall level of outcross pollination.

If the species is strongly outcrossing and only sets pods after pollination by biotic vectors, we postulate that the pattern of pod set should be patchy because at the visit frequencies we report in this paper it is unlikely, for both stochastic and micro-environmental reasons, that pod set would be even across the whole crown of a tree. We could not quantify such pattern in pod set but we are able to present photographic evidence of trees in full flower and again at pod maturation (pl. 1).

The literature suggests that outcrossed flowers of *A. dealbata* produce a higher number of full seed per pod than selfs (Rodger & Johnson 2013, Correia *et al.* 2014), so full seeds per pod may be taken as a rough indication of the level of outcrossing. We determined this trait for pods harvested from the top, middle and bottom of crowns of five trees at Site 4. These trees ranged in total height from 12–24 m. Two separate samples of pods at each level, ranging in number from 48 to over 500, were dried to open and all seeds extracted and classified as one of four categories: (1) full, black 5 mm; (2) full, brown 5 mm; (3) small, black 3 mm; (4) vestigial, < 2 mm. The total number was counted but only category 1 considered to be good seed. The numbers of total and good seed per pod were then calculated together with the proportion of good seed as a percentage of total seed. The data sets for these three variates were analysed using ANOVA, with tree and height level as the treatment factors in factorial combination.

RESULTS

The trees at Site 1 flowered over 76 days between 16 July and 29 September with a median date for peak flowering of 24 August. The mean number of days that a tree carried some open flowers was 51 and, although there was variation among trees, no genets were fully temporally isolated.

During the flowering period the mean minimum and maximum daily temperatures at the Bureau of Meteorology (Ellerslie Rd site) were 6.4°C and 15.1°C. Mean temperature at 9 am was 9.5°C rising to 13.1°C at 3 pm; at that time mean wind speed was 31 km h^{-1} with a maximum of 71 km h^{-1} and a mean relative humidity of 53.5% (minimum 25%). During the flowering season a total of 91.6 mm of rain fell with 0.2 mm or more on 41 of the 71 days (58%). Weather conditions on bird observation days are noted in appendix 2 together with the respective flowering phenology records.

Invertebrate visitors

For invertebrates, we documented visits by larger mobile and potentially pollinating insects and also the array of small invertebrates which fell from the blossoms when the branches were beaten and are assumed to be the target of foraging birds. Potentially pollinating insects from 29 Families within seven Orders were observed on flowering branches of *A. dealbata* (appendix 1). Of these, 41% of individuals were Dipterans (55% of which were Syrphidae) (table 2a) and 41% were Hymenoptera (of which 38% were Honey

Bees *Apis mellifera* and 15% native bees). Coleoptera was a distant third in terms of frequency.

A diverse array of small invertebrates of varying developmental stages (appendix 1) was captured when flowering branches were beaten. In all, 47 Families from 10 Orders were represented but 94% of the total catch came from five Orders which each contributed between 11 and 25% (table 2b). Within the more common Orders the most numerous Families were: Coleoptera– Chrysomelidae (leaf beetles), Diptera– Chironomidae (Midges), Hemiptera– Psyllidae (psyllids), Hymenoptera– Platygastridae (parasitoid wasps) and Araneae– Thomisidae (crab spiders). On the non-flowering tree, adjacent to flowering Tree 1, there was a reduced diversity of taxa. Over the four days when both trees were sampled, Tree 1 yielded 106 invertebrates from 19 families while the non-flowering tree collection was only 30 individuals from 11 Families (appendix 1).

Bird visitors

Across Sites 1 and 2 a total of ten bird species was seen to make contact with the inflorescences of *A. dealbata* trees during one or more of the 10-minute observation periods. A further 11 species perched on branches of *A. dealbata* trees but flew off without making contact with inflorescences or exhibiting feeding behaviour (table 3).

Of the ten species that contacted inflorescences, six did so only occasionally, briefly and incidentally, during the course of feeding on flowers of an adjacent *Banksia marginata* tree (Eastern Spinebill); hawking airborne insects around the tree crowns (Grey Fantail and Black-headed Honeyeater); or as a result of chasing or mating-related social behaviour (Yellow-throated Honeyeater, New Holland Honeyeater and Yellow Wattlebird).

Four bird species did actively work the flowering crowns of *A. dealbata*, moving between adjacent trees while doing so. On some days they remained in the crowns for the entire 10-minute observation period and beyond. Brown Thornbills and Silvereyes appeared to be searching for and feeding on small invertebrates (pl. 3) while the Green Rosellas and Eastern Rosellas were observed to feed within the blossom-bearing crowns, selectively picking and consuming individual pollen bearing and/or galled flower-heads (pl. 2). The presence of clipped branchlets on the ground below 97% of the trees at Site 1 (table 4) suggested that the Green Rosellas visited there more frequently than we were able to observe. Green Rosellas commenced visiting OPs at Site 1 once anthesis had commenced on some of the trees and were not observed on trees which were past peak flowering (fig. 1). Brown Thornbill visits were concentrated from early to peak flowering, but they also made a few visits before flowering commenced and after it had completed (fig. 1).

At Site 2, Silvereyes showed similar foraging behaviour to Brown Thornbills as did the Eastern Rosella to that of the Green Rosellas. At Site 3, Brown Thornbills were observed feeding among the *A. dealbata* flowers, moving from crown to crown during the 10-minute observation periods on seven of the ten observation days. Grey Fantails made accidental contact with the inflorescences on one day while hawking insects around the crowns. Although

TABLE 2a – Total flower visitors during 10-minute observation periods per tree on seven days throughout the 2018 flowering season.

		Observation Date							
Order	Family	20 Jul	7 Aug	14 Aug	24 Aug	4 Sep	11 Sep	18 Sep	Total
Diptera		2	0	1	8	22	14	9	56
	(Syrphidae	0	0	0	2	12	11	6	31)
Hymenoptera		0	0	2	22	11	14	6	55
	(Apidae	0	0	2	15	2	2	0	21)
	(Halictidae	0	0	0	2	1	1	2	6)
	(Colletidae	0	0	0	0	1	1	0	2)
Coleoptera		0	0	3	1	3	7	2	16
Hemiptera		3	0	0	0	0	0	1	4
Lepidoptera		0	0	1	0	0	1	0	2
Neuroptera		1	0	0	0	0	0	0	1
Thysanoptera		0	0	0	0	0	1	0	1
Total		**6**	**0**	7	31	36	37	18	135
Flowering status[1]		5	35	60	100	85	65	25	–

[1] Mean % of flowers across sample trees which were judged to be fully opened (100 = peak flowering).
Data from four trees were pooled. Within the total observations for Diptera and Hymenoptera the numbers for Families with highest putative pollination potential according to the literature are also detailed. For more complete data see Appendix 2.

TABLE 2b – Numbers of small invertebrates captured by beating flower-bearing branches throughout the 2018 flowering season.

	Capture date									
Order	3 July	9 Jul	20 Jul	7 Aug	14 Aug	24 Aug	4 Sep	11 Sep	18 Sep	Total
Hymenoptera	5	13	9	13	28	32	26	33	41	200
Hemiptera	12	24	13	18	13	24	16	23	26	169
Diptera	17	26	15	33	11	18	15	18	9	162
Coleoptera	3	11	7	9	12	26	22	15	17	122
Araneae	7	9	6	12	13	11	17	6	9	90
Neuroptera	0	2	1	3	3	3	6	1	3	22
Acari	1	0	1	2	2	5	3	0	0	14
Thysanoptera	0	0	0	0	2	0	4	2	0	8
Lepidoptera	0	0	0	1	1	0	2	1	2	7
Blattodea	0	0	0	0	0	0	0	0	2	2
Total	**45**	**85**	**52**	**91**	**85**	**119**	**111**	**99**	**109**	**796**
Flowering status[1]	0	0	5	35	60	100	85	65	25	–

[1] Mean % of flowers across sample trees which were judged to be fully opened (100 = peak flowering). Data from four trees pooled. For details see Appendix 1.

PLATE 3 — Brown Thornbill feeding within the blossom of *A.dealbata* (photo M. Brown).

Green Rosellas were not observed to visit the flowering crowns, the presence of clipped branchlets under 34% of nearby trees (table 4) indicated that they had made recent feeding visits.

Indirect evidence of rosella feeding

The surveys of clipped flowering branchlets on the ground below flowering *A. dealbata* trees at nine locations (table 4) suggested that Green Rosellas, and possibly Eastern Rosellas, fed on many of the trees. The proportion of trees below which clip could be detected ranged from 6% at Waverley Flora Reserve to 97% at Site 1, with a mean value across all nine sites of 57 % (table 4).

Pollen carried by birds

Seventeen birds were caught and swabbed (10 at Site 1 over 3 days and 7 at Site 5 over 2 days) and nine of these carried pollen from various plants (tables 5a and 5b). *Acacia* polyads were recovered from five birds and on three of these (a Green Rosella and two Brown Thornbills) this was the only pollen present.

Pollen viability on feathers

The germination percentage of polyads experimentally placed on bird feathers was highest when freshly removed from the anthers. After 48 h incubation at ambient temperature, 60% had germinated (fig. 2). Thereafter viability declined more or less linearly to 16% at Day 12, with no germination of the final sample taken at Day 17.

TABLE 3 – Number per species for birds observed at two sites through the period of the study, indicating behavioural characteristics.

Common Name	Scientific name	Site 1 – Knocklofty			Site 2 – Mt Nelson		
		Perching on branches	Contacting flowers	Feeding on/ among inflor-escences	Perching on branches	Contacting flowers	Feeding on/ among inflor-escences
Psittaciformes							
Green Rosella	*Platycercus caledonicus*	19	19	19	19	19	19
Eastern Rosella	*Platycercus eximius*	–	–	–	4	4	4
Musk Lorikeet	*Glossopsitta concinna*	–	–	–	4	–	–
Passeriformes							
Silvereye	*Zosterops lateralis*	–	–	–	33	24	24
Brown Thornbill	*Acanthiza pusilla*	14	14	14	5	5	5
Yellow-throated Honeyeater	*Nesoptilotus flavicollis*	5	*	–	10	*	–
Yellow Wattlebird	*Anthochaera paradoxa*	6	*	–	7	*	–
New Holland Honeyeater	*Phylidonyris novaehollandiae*	–	–	–	9	*	–
Crescent Honeyeater	*Phylidonyris pyrrhopterus*	–	–	–	1	–	–
Eastern Spinebill	*Acanthorhynchus tenuirostris*	3	*	–	4	–	–
Black-headed Honeyeater	*Melithreptus affinis*	1	–	–	2	*	–
Strong-billed Honeyeater	*Melithreptus validirostris*	2	–	–	–	–	–
Scarlet Robin	*Petroica boodang*	7	–	–	–	–	–
Grey Fantail	*Rhipidura albiscapa*	3	*	–	–	–	–
Superb Fairy-wren	*Malurus cyaneus*	5	–	–	–	–	–
Grey Currawong	*Strepera versicolor*	2	–	–	1	–	–
Grey Butcherbird	*Cracticus torquatus*		–	–	1	–	–
Forest Raven	*Corvus tasmanicus*	1	–	–	–	–	–
Golden Whistler	*Pachycephala pectoralis*	1	–	–	–	–	–
Grey Shrike-thrush	*Colluricincla harmonica*	1	–	–	–	–	–
Common Blackbird	*Turdus merula*	1	–	–	1	–	–
Not identified		7	–	–	–	–	–

* incidental contact only

TABLE 4 – Surveys of clip under *A. dealbata* trees at nine locations around Hobart, indicating feeding of Rosellas.

Transect No.	Date	Location	No. of trees with clip under tree	No. of trees without clip	Percentage of trees with clip (%)
1	Aug 12	Knocklofty[a] (Site 1)	31	1	97
2	Aug 13	Peter Murrell Reserve[1]	36	6	86
3	Aug 17	Waverley Flora Reserve	2	29	6
4	Aug 18	Geilston to Shag Bay walk	2	21	9
5	Aug 28	31 Turnip Fields Rd (Site 4)	32	34	48
6	Aug 29	Lenah Valley Creek track	51	20	72
7	Aug 29	30 Turnip Fields Rd (Site 4)	16	15	52
8	Aug 30	Cleggs Rd, Ferntree (Pipeline Track)	20	8	71
9	Sep 02	Lower Longley (Site 3)	10	19	34
		Total	**200**	**153**	**57**

[1] Green Rosellas seen feeding on *A. dealbata* crowns at these locations at the time of survey.

TABLE 5a – Numbers of pollen grains observed on birds captured at Waterworks Reserve.

Date (2018)	Species	Pollen
22 Jul	Crescent Honeyeater	65 *Banksia*, 3 *Pinus*, 1 *Eucalyptus*?
22 Jul	Crescent Honeyeater	334 *Banksia*
22 Jul	Scarlet Robin	0
20 Aug	Dusky Robin	0
20 Aug	Eastern Spinebill	414 *Ulex*
20 Aug	Green Rosella	15 *Acacia*
20 Aug	Crescent Honeyeater	28 *Banksia*

TABLE 5b – Numbers of pollen grains observed on birds captured at Knocklofty Reserve.

Date (2018)	Species	Pollen
14 Aug	Superb Fairy-wren	0
14 Aug	Brown Thornbill	0
14 Aug	Brown Thornbill	0
14 Aug	Brown Thornbill	0
22 Aug	Crescent Honeyeater	90 *Ulex*, 439 *Melaleuca*, 6 *Banksia*, 2 *Acacia*
22 Aug	Yellow-throated Honeyeater	6 *Acacia*, 9 Myrtaceae
22 Aug	Brown Thornbill	2 *Acacia*
29 Aug	Brown Thornbill	6 *Acacia*
29 Aug	Superb Fairy-wren	0
29 Aug	Superb Fairy-wren	0

TABLE 6 – Mean number of full seeds from pods harvested at three levels within the crowns of five trees at Site 4.

Tree	Tree ht (m)	Full seed/pod by crown position: Total no. pods extracted	Low (%)	Mid (%)	Top (%)	Weighted mean
1	24	623	3.0 (84)	3.3 (75)	3.7 (67)	3.3
2	13	521	3.1 (70)	3.8 (71)	3.9 (72)	3.6
3	15	808	1.3 (43)	1.4 (42)	1.4 (43)	1.4
4	19	817	3.6 (62)	3.5 (78)	3.9 (82)	3.7
5	20	1680	4.5 (81)	4.0 (77)	2.5 64)	3.7

Pooled data from two separate samples of pods at each level per tree, also expressed as a % of the total seed per pod. Differences between trees in number and % full seed significant, $p < 0.001$. No significant variation between levels within trees or tree x level interaction, $p > 0.05$.

FIG. 2 — Viability over time of pollen placed on feathers at Day 0 and re-sampled at intervals up to 17 days. Material was kept dry and at ambient temperature.

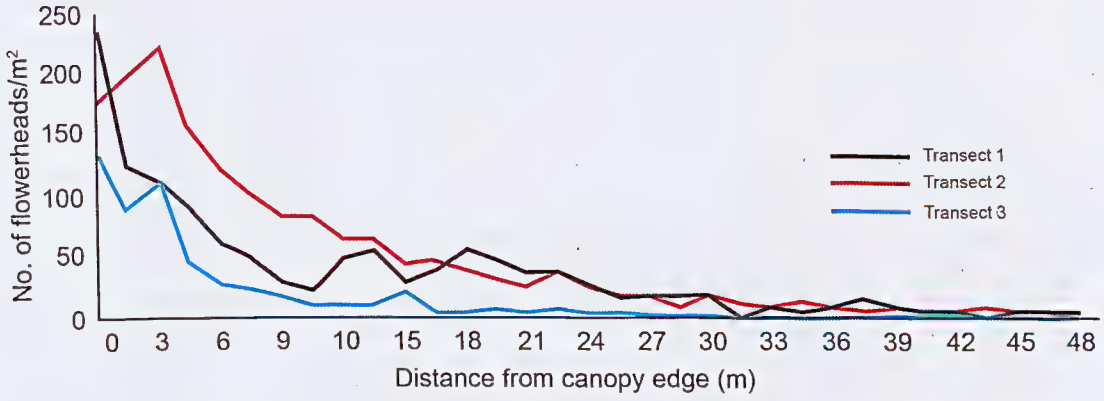

FIG. 3 — Dispersion of detached flower-heads on three transects run perpendicular to forest margin across open paddock at Site 4.

Wind dispersal of flower-heads

Head dispersal was surveyed on 17 August after a period of particularly windy weather. On the six previous days, maximum daily gusts at Ellerslie Rd ranged between 44 and 102 km h^{-1}. For transects 1 and 2 which were perpendicular to the forest margin across open grassland, over 80% of heads fell within 15 m of the canopy margin, though occasional heads were still detected at the limit of observation (49.5 m) (fig. 3). The greater variability of Transect 3 could be attributable to the effect of several trees about 30 m away to the side of this transect.

Pod and seed production

Both flowering and mature pod production were essentially uniform within a tree crown as can be seen from the photographs of two trees which flowered heavily at Site 4 (pl. 1). Pod production from the very topmost branches is interesting in that it seems unlikely that, under the commonly prevailing weather conditions, these very exposed locations would be favoured as feeding sites by any of the insect visitors or even the birds; however, this is speculation. The mean number of full seed per pod was quite uniform among trees except for Tree 3 which was highly parasitised and only averaged 1.4 full seeds per pod, less than half the number of the nearby Trees 4 and 5 (table 6). Among the height levels in the crown there was no significant pattern of variation ($p > 0.05$, table 6). Although the pods from the top of Tree 5 had fewer seeds than lower in the canopy, it should be noted that this was the earliest maturing individual and it is possible that some seeds were already shedding from the dehiscing pods by the time we made the harvest.

The ovaries of *A. dealbata* flowers contain an average of 13 ovules (Correia *et al.* 2014). In the current study about one-third (4.26) were fertilised and developed to the point they could be classified as a seed, of which an average of 74% or 3.14 per pod were full.

DISCUSSION

The floral biology of *A. dealbata* is most closely aligned with an insect pollination syndrome; however, the weather conditions during the late winter/early spring flowering season are not conducive to insect flight activity and very few such visitors were observed until late in the flowering season (table 2a). It appears very unlikely that these numbers were sufficient to have a major impact as pollinators. A more objective determination of this point would require estimation of both flower numbers and the period over which individual stigmas remain receptive and is outside the scope of the present study. The introduced honey bee was the most common insect visitor, as was also the case where the species is growing as an exotic in South Africa (Rodger & Johnson 2013), Portugal (Correia *et al.* 2014) and Italy (Giuliani *et al.* 2016), but the maximum number of individuals seen in a single observation period was only 15 across the four trees at the time of peak flowering (table 2a). As in an earlier study of three other species of *Acacia* in Tasmania (Hingston & McQuillan 2000), small numbers of native bees, flies and beetles were also observed visiting the flowers. Of the native bees, which Bernhardt and Walker (1984) regarded as extremely significant pollinators of *Acacia* species, we observed only six individual Halictidae and two Colletidae over the whole study period. Stone *et al.* (2003) reported that over a range of *Acacia* species native bees represented only 1–5% of flower visits, so the generalisation regarding importance of native bees as pollinators is worth revisiting at least for cool temperate Australia. In a study of two spring/summer flowering *Acacia* species in Western NSW (Gilpin *et al.* 2014) only honey bees were found in high abundance and only they and two beetle species carried pollen on their bodies. Syrphid flies, also noted by Bernhardt (1989) as potentially important vectors, were the most common Dipteran visitors to the study trees (table 2a). *A. dealbata* is the earliest flowering of all Tasmanian acacias and if outcrossing by insects was of critical evolutionary importance then we might expect that selection pressure on the phenology would have caused a shift to later flowering.

The species does not produce nectar from either flowers or extra-floral nectaries and this, together with the yellow flowers and distinctive scent, is inconsistent with traditional bird pollination syndromes which are characterised by the production of abundant nectar to support energetic needs, red colour, and little scent (Faegri & van der Pijl 1979, Nadra *et al.* 2018). However, since some bird species were observed to consistently feed on and among the flowers (table 3) they must clearly be deriving some benefit. Brown Thornbills and Silvereyes have previously been documented working among flowers of other *Acacia* species (Ford & Forde 1976, Knox *et al.* 1985, Vanstone & Paton 1988), but in those cases they were feeding primarily from extrafloral nectaries which are vestigial in *A. dealbata* (Marazzi *et al.* 2019). However, Silvereyes and a Striated Thornbill *Acanthiza lineata* also occasionally pecked at flowers of *A. pycnantha*, and invertebrates and pollen were both suggested as the possible food items targeted (Ford & Forde 1976, Vanstone & Paton 1988). Our data clearly show that small invertebrates are a likely food source because of their abundance within inflorescences of *A. dealbata.* In a study in Victoria, Haylock and Lill (1988) found that thornbill diet was dominated by Coleoptera and Hymenoptera which we have shown are common on *A. dealbata* flowering branches at Site 1 (table 2a). The great majority of taxa we collected were within the size range of <4 mm which Tullis *et al.* (1982) reported as making up 72% of the diet of two species of thornbill in Western Australia.

The importance of the micro-habitat of *Acacia* flowers to small invertebrates is evidenced by the greater diversity on flowering than non-flowering crowns (appendix 1). On a flowering tree 45% of the total catch was Chrysomelid beetles in larval form, Chironomid midges, and comb-footed spiders (Theridiidae), but of these taxa, only two beetle larvae were present in samples from an adjacent non-flowering tree, where 50% of individuals were Psyllids. These differences are explainable in terms of feeding preferences. Larvae of some species of Chironomid may feed on pollen (Armitage *et al.* 1995); spiders presumably prey on other small invertebrates which are present in greater numbers on the flowering tree; many beetle larvae including Chrysomelids are adapted to consuming pollen (Bernhardt 1989) and can sometimes cause very significant damage to flowers of *A. dealbata* by eating the filaments, anthers and styles (Griffin unpubl. data). In contrast, the Psyllids are sap suckers and presumably vegetative shoots without flowers are also attractive to them. The seasonal pattern of occurrence of the small invertebrates was quite different to that of the larger insect flower visitors. Populations of the former were present within the inflorescences from well before flowering began (table 2b). These increased once trees began to flower, after which the total catch per day across the four sample trees was quite uniform through the rest of the season, though the maximum number was recorded at the time of peak flowering. In contrast very few potential pollinating insects were recorded until the trees reached peak flowering and numbers declined again towards the end of the season (table 2a). The extended availability of small-invertebrate food explains why Brown Thornbills were also observed among the blossom throughout the complete season (fig. 1).

The foraging behaviour of Green Rosellas at flowers of *A. dealbata* was very different to that of Silvereyes and Brown Thornbills as they were observed to harvest and ingest whole flower-heads at a stage prior to complete anthesis (fig. 2). Several previously documented cases of bird pollination of nectarless flowers also reported that floral tissues were consumed (Sérsic & Cocucci 1996, Dellinger *et al.* 2014, Nadra *et al.* 2018). We are unable to comment on the relative nutritional value of the floral components and/or parasitising gall insects, but it is known that two other species of parrot occurring in our study region (Swift Parrot *Lathamus discolor* and Musk Lorikeet *Glossopsitta concinna*) intentionally consume and digest the pollen of *Eucalyptus* (Gartrell & Jones 2001, Hingston *et al.* 2004a). Green and Eastern Rosellas both have been observed foraging on open flowers of *Eucalyptus* (Hingston & Potts 2005), so the pollen is likely to be important as a food resource, a conclusion consistent with the decline in the bird visits at Site 1 after peak flowering (fig. 1). Magrath and Lill (1983) observed similar feeding behaviour in Crimson Rosellas (*P. elegans)* on eucalypts in Victoria, concluding that flower buds and associated gall larvae formed nearly 50% of their seasonal diet. These authors noted that, consistent with our observations, feeding rosellas always drop debris, so relative frequency of occurrence on the ground was used in estimating the diet in that study. Pollination by flower-consuming Meyer's Parrots *Poicephalus meyeri* has also been documented in African 'acacias' (Boyes & Perrin 2009).

Although these two rosella species are destructive foragers, they most likely pollinate numerous flowers as they clamber among the blossom and the prevalence of clippings beneath many flowering *A. dealbata* trees (table 4) shows that such activities are common and widespread. Given the mass flowering and characteristically low flower: fruit ratio in this and other *Acacia* species, the loss of some flowers may be an affordable price to pay for the pollination services provided by these species.

The feeding habits of these two functional groups of birds explains their presence in and among the flowers but to act as pollen vectors they must pick up pollen in the process. We were able to recover small amounts of *Acacia* pollen from the feathers of Green Rosellas and Brown Thornbills (table 5a, 5b) and have demonstrated that once pollen is removed from the anthers it can retain over half its viability for at least seven days (fig. 2), substantially longer than the three days reported by Sedgley and Harbard (1993) for tropical acacia taxa. Presumably this is time enough for birds to make many inter-tree visits before pollen viability is lost. Although both the number of birds sampled and the pollen recovered from those individuals was small, the data support the contention that these birds play a role in outcross pollination. The clip surveys (table 4) found that 57% of the *A. dealbata* trees across the region had been visited by rosellas which are strong-flying birds capable of many inter-tree movements. However, the numbers of individuals observed foraging on or among the flowers was

small (table 3). Thornbills and Silvereyes were relatively more numerous at all three observation sites but it seems unlikely that either functional group could have been solely responsible for the total number of pollen transfer events needed to set the observed heavy fruit crop.

Possibility of wind pollination

Though the detached flowerheads have a substantial mass and over open ground were mostly deposited within 20 m of the crowns (fig. 3), this distance is more than enough for pollen transfer within stands of *A. dealbata* given the windy conditions which are prevalent during the flowering season in this region (Bureau of Meteorology 2018). It remains to be demonstrated that polyads are also blown off the open anthers under some conditions but the literature suggests that this is possible. Flowers of *Acacia* do not exhibit morphological traits normally characteristic of wind pollinated plants (Sedgley & Griffin 1989, Gibson *et al.* 2011) and the polyads which average 46 µm in diameter (Nghiem *et al.* 2018) are larger than the 25 µm that is typical of the wind pollination syndrome (Knox 1979). However, as noted by Kendrick (2003), the disc shape of the polyad may have aerodynamic properties which serve to counteract their relatively large size. Reviews of the pollination ecology of the genus by Bernhardt (1989) and Stone *et al.* (2003) do not discuss the possibility but there are some records of wind dispersal of *Acacia* pollen (Moncur *et al.* 1991, Smart & Knox 1979, Kendrick 2003, Giovanetti *et al.* 2018) and allergy to airborne pollen has been reported from a number of countries (Ariano *et al.* 1991). Millar *et al.* (2014) offered long-distance wind-mediated dispersal of small insects as an explanation for their finding of substantial gene flow between dispersed populations of *A. woodmaniorum* in Western Australia. While Keighery (1980) listed *Acacia* as being primarily insect pollinated in that region, he acknowledged that bird and wind transference could play a minor role in pollination and noted that "more observations are needed on (pollen vectors) of this important genus".

Factors determining efficiency of wind pollination are very different from those with biotic vectors. There is no issue of population number in pollen transfer since wind is a more or less general phenomenon in the region during the flowering season of *A. dealbata*. While biotic vectors would target flowers during feeding, wind dispersion is effectively random in space but with density in the air as the major determinant of the probability that a polyad would land on a receptive style. It is likely that geitonogamous pollination (transfer of pollen between flowers within a single genet) within a tree crown or between ramets of a clone would be a much more frequent outcome than transfer between different genets, so impact of vector type on the breeding system needs to be considered.

Studies of the species as an exotic in South Africa (Rodger & Johnson 2013) and Portugal (Correia *et al.* 2014) found that *A. dealbata* is partially self-fertile and demonstrated that autonomous pollination is possible (see also review by Gibson 2011), although Broadhurst *et al.* (2008) found that only outcrossed seed were produced under natural pollination conditions in populations of the species in New South Wales. Mechanisms favouring preferential development of outcrosses may operate in *Acacia* as in *Eucalyptus* (Griffin *et al.* 1987) but this remains to be demonstrated. If the plants are strongly reliant on biotic outcross pollination in order to set seed and pollinators are scarce relative to the large number of flowers produced, then we would expect to see a patchy distribution of pods within each tree crown. The pod and seed production data are therefore useful in gaining an appreciation of the likelihood of such pollen limitation. We were not able to quantify total flower or pod crops per tree but it was evident from inspection that pod set in 2018 was generally both heavy and uniformly distributed within the crowns to the very topmost branches (pl. 1 and table 6). The consistent uniformity of production of full seed pods throughout the crown (table 6) strengthens the possibility that wind pollination may be important and is in contrast to *Eucalyptus globulus*, a common dominant tree species in southeast Tasmania which is known to be pollinated by both birds and insects (Hingston *et al.* 2004b). In that species Hingston and Potts (2005) found significantly less flower-visiting bird activity in the lower than higher halves of the crowns and Patterson *et al.* (2004) showed this pattern was associated with higher outcrossing rates for the seeds from the upper part of the canopy. In our study, observed population mean number of full seeds per pod of 3.14 (table 6) is substantially higher than the maximum mean of 1.2 found in the ten NSW populations studied by Broadhurst and Young (2006), or the 1.04 in an exotic population in South Africa (Rodger & Johnson 2013) and can be taken as another indication of probable high levels of outcrossing. Genetic analysis of seed samples from Site 4, to be published elsewhere, has confirmed this assumption. The mating system is definitely strongly outcrossing ($t = 0.89 \pm 0.92$) (R. Vaillancourt unpubl. data).

In summary, the study failed to definitively identify any one major pollinator of *A. dealbata* in this environment yet we infer from the heavy and uniformly distributed pod crops and from the genetic analysis, that outcrossing must be occurring. The species is best viewed as having a generalist pollination system, a conclusion reached by the study of Montesinos *et al.* (2016) in exotic populations in Portugal and consistent with many other plant species in southern Tasmania (Hingston & McQuillan 2000). Evolution of reproductive attributes amenable to pollination by a range of different vectors may be of adaptive advantage (Hingston & McQuillan 2000, Ollerton *et al.* 2009), with the consequence that current major pollen vectors cannot be predicted from consideration of floral traits alone.

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REFERENCES

Ariano, R., Panzani, R.C. & Amedeo, J. 1991: Pollen allergy to Mimosa (*Acacia-floribunda*) in a mediterranean area – an occupational-disease. *Annals of Allergy* **66**: 253–256.

Armitage, P.D., Cranston, P.S. & Pinder, L.C.V. 1995: *The Chironomidae: biology and ecology of non-biting midges.* Chapman & Hall, London: 572 pp.

Bernhardt, P. 1987: A comparison of the diversity, density, and foraging behavior of bees and wasps on Australian Acacia. *Annals of the Missouri Botanical Garden* **74**: 42–50.

Bernhardt, P. 1989: The floral ecology of Australian Acacia. *In* Stirton, C.H. & Zarucchi, J.L. (eds.): *Advances in Legume Biology. Monographs in Systematic Botany from the Missouri Botanical Garden* **29**: 263–281.

Bernhardt, P. & Walker, K. 1984: Bee foraging on 3 sympatric species of Australian Acacia. *International Journal of Entomology* **26**: 322–330.

Boland, D., Brooker, M., Chippendale, G., Hall, N., Hyland, B., Johnston, R., Kleinig, D., McDonald, M. & Turner, J. 2006: *Forest trees of Australia (Fifth Edition),* CSIRO, Melbourne: 568 pp.

Bureau of Meteorology 2018: 'Hobart, Tas - Daily Weather Observations.' Available at: http://www.bom.gov.au/climate/dwo/IDCJDW7021.latest.shtml

Boughton, V. 1981: Extrafloral nectaries of some Australian phyllodineous Acacias. *Australian Journal of Botany* **29**: 653–664.

Boyes, R.S. & Perrin, M.R. 2009: Do Meyer's Parrots *Poicephalus meyeri* benefit pollination and seed dispersal of plants in the Okavango Delta, Botswana? *African Journal of Ecology* **48,** 769–782.

Broadhurst, L.M. & Young, A.G. 2006: Reproductive constraints for the long-term persistence of fragmented *Acacia dealbata* (Mimosaceae) populations in southeast Australia. *Biological Conservation* **133**: 512–526.

Broadhurst, L.M., Young, A.G. & Forrester, R. 2008: Genetic and demographic responses of fragmented *Acacia dealbata* (Mimosaceae) populations in southeastern australia. *Biological Conservation* **141**: 2843–2856.

Correia, M., Castro, S., Ferrero, V., Crisóstomo, J.A. & Rodríguez-Echeverría, S. 2014: Reproductive biology and success of invasive Australian Acacias in Portugal. *Botanical Journal of the Linnean Society* **174**: 574-588.

Dellinger, A.S., Penneys, D.S., Staedler, Y.M., Fragner, L., Weckwerth, W. & Schönenberger, J. 2014: A specialized bird pollination system with a bellows mechanism for pollen transfer and staminal food body rewards. *Current Biology* **24:** 1615–1619.

Faegri, K. & van der Pijl, L. 1979: *The Principles of Pollination Ecology.* Pergamon Press, Oxford: 244 pp.

Ford, H.A. & Forde, N. 1976: Birds as possible pollinators of *Acacia pycnantha. Australian Journal of Botany* **24**: 793–795.

Ford, H.A., Paton, D.C. & Forde, N. 1979: Birds as pollinators of Australian plants. *New Zealand Journal of Botany* **17**: 509–519.

Fuentes-Ramirez, A., Pauchard, A., Cavieres, L.A. & Garcia, R.A. 2011: Survival and growth of *Acacia dealbata* vs. native trees across an invasion front in south-central Chile. *Forest Ecology and Management* **261**: 1003–1009.

Gartrell, B.D. & Jones, S.M. 2001: *Eucalyptus* pollen grain emptying by two Australian nectarivorous psittacines. *Journal of Avian Biology* **32:** 224–230.

Gibson, M.R., Richardson, D.M., Marchante, E., Marchante, H., Rodger, J.G., Stone, G.N., Byrne, M., Fuentes-Ramírez, A., George, N., Harris, C., Johnson, S.D., Roux, J.J.L., Miller, J.T., Murphy, D.J., Pauw, A., Prescott, M.N., Wandrag, E.M. & Wilson, J.R.U. 2011: Reproductive biology of Australian Acacias: Important mediator of invasiveness? *Diversity and Distributions* **17**: 911–933.

Gilpin, A.M., Ayre, D.J. & Denham, A.J. 2014: Can the pollination biology and floral ontogeny of the threatened *Acacia carneorum* explain its lack of reproductive success? *Ecological Research* **29**: 225–235.

Giovanetti, M., Ramos, M. & Máguas, C. 2018: Why so many flowers? A preliminary assessment of mixed pollination strategy enhancing sexual production of the invasive *Acacia longifolia* in Portugal. *Web Ecology* **18:** 47–54.

Giuliani, C., Giovanetti, M., Foggi, B. & Mariotti Lippi, M. 2016: Two alien invasive acacias in Italy: Differences and similarities in their flowering and insect visitors. *Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology* **150**: 285–294.

Griffin, A.R., Moran, G.F. & Fripp, Y.J. 1987: Preferential outcrossing in *Eucalyptus regnans* F.Muell. *Australian Journal of Botany* **35:** 465–475.

Griffin, A.R., Hingston, A.B. & Ohmart, C.P. 2009: Pollinators of *Eucalyptus regnans* (Myrtaceae), the world's tallest flowering plant species. *Australian Journal of Botany* **57**: 18–25.

Griffin, A.R, Midgley, S., Bush, D., Cunningham, P. & Rinaudo, A. 2011: Global uses of Australian acacias–recent trends and future prospects. *Diversity and Distributions* **17**: 837–847.

Harwood, C.E., Griffin, A.R., Harbard, J.L. & Nghiem, Q.C. 2018: Studies on triploid clones of Silver Wattle (*Acacia dealbata*) in southeast Tasmania. *The Tasmanian Naturalist* **140**: 107–123.

Haylock, J. & Lill, A. 1988: Winter ecological energetics of 2 passerine bird species in temperate wet forest. *Wildlife Research* **15**: 319 –329.

Hingston, A.B. & McQuillan, P.B. 2000: Are pollination syndromes useful predictors of floral visitors in Tasmania? *Austral Ecology* **25:** 600–609.

Hingston, A.B., Gartrell, B.D. & Pinchbeck, G. 2004a: How specialized is the plant-pollinator association between *Eucalyptus globulus* ssp. *globulus* and the swift parrot *Lathamus discolor*? *Austral Ecology* **29:** 624–630.

Hingston, A.B., Potts, B.M. & McQuillan, P.B. 2004b: Pollination services provided by various size classes of flower visitors to *Eucalyptus globulus ssp globulus* (Myrtaceae). *Australian Journal of Botany* **52**: 353–369.

Hingston, A.B. & Potts, B.M. 2005: Pollinator activity can explain variation in outcrossing rates within individual trees. *Austral Ecology* **30:** 319–324.

Keighery, G.J. 1980: Bird pollination in south western Australia: A checklist. *Plant Systematics and Evolution* **135**: 171–176.

Kendrick, J. 2003: Review of pollen-pistil interactions and their relevance to the reproductive biology of *Acacia. Australian Systematic Botany* **16**: 119–130.

Kitchener, A. & Harris, S. 2013: *From forest to fjaeldmark: Descriptions of Tasmania's vegetation,* Department of Primary Industries, Parks, Water and Environment, Tasmania: 14 pp.

Knox, R.B. 1979: 'Pollen and Allergy' Studies in Biology No. 107, Edward Arnold Ltd., London: 64 pp.

Knox, R.B., Kenrick, J., Bernhardt, P., Marginson, R., Beresford, G., Baker, I. & Baker, H.G. 1985: Extrafloral nectaries

as adaptations for bird pollination in *Acacia terminalis*. *American Journal of Botany* **72**: 1185–1196.

Magrath, R. & Lill, A. 1983: The use of time and energy by the Crimson Rosella in a temperate wet forest in winter. *Australian Journal of Zoology* **31**: 903–912.

Marazzi, B., Gonzalez, A.M., Delgado-Salinas, A., Luckow, M.A., Ringelberg, J.J. & Hughes, C.E. 2019: Extrafloral nectaries in leguminosae: Phylogenetic distribution, morphological diversity and evolution. *Australian Systematic Botany* **32**: 409–458.

Millar, M.A., Coates, D.J. & Byrne, M. 2014: Extensive long-distance pollen dispersal and highly outcrossed mating in historically small and disjunct populations of *Acacia woodmaniorum* (fabaceae), a rare banded iron formation endemic. *Annals of Botany* **114**: 961–971.

Moncur, M.W., Moran, G.F. & Grant, J.E. 1991: Factors limiting seed production in *Acacia mearnsii*. *Advances in Tropical Acacia Research* **35**: 20–25.

Montesinos, D., Castro, S. & Rodríguez-Echeverría, S. 2016: Two invasive Acacia species secure generalist pollinators in invaded communities. *Acta Oecologica* **74**: 46–55.

Nadra, M.G., Giannini, N.P., Acosta, J.M. & Aagesen, L. 2018: Evolution of pollination by frugivorous birds in Neotropical Myrtaceae. *PeerJ* **6**, e5426.

Nghiem, Q., Griffin, A., Harwood, C., Harbard, J., Le, S., Price, A. & Koutoulis, A. 2018: Occurrence of polyploidy in populations of *Acacia dealbata* in south-eastern Tasmania and cytotypic variation in reproductive traits. *Australian Journal of Botany* **66**: 152–160.

Ollerton J, Alarcón R, Waser, N.M., Price, M.V., Watts, S., Cranmer, L., Hingston, A., Peter, C.I. & Rotenberry, J. 2009: A global test of the pollination syndrome hypothesis. *Annals of Botany* **103**: 1471–1480.

Patterson, B., Vaillancourt, R.E., Pilbeamb, D.J. & Potts, B.M. 2004: Factors affecting variation in outcrossing rate in *Eucalyptus globulus*. *Australian Journal of Botany* **52**: 773–780.

Rodger, J.G. & Johnson, S.D. 2013: Self-pollination and inbreeding depression in *Acacia dealbata*: Can selfing promote invasion in trees? *South African Journal of Botany* **88**: 252–259.

Rosas-Guerrero, V., Aguilar, R., Martén-Rodríguez, S., Ashworth, L., Lopezaraiza-Mikel, M., Bastida, J.M. & Quesada, M. 2014: A quantitative review of pollination syndromes: do floral traits predict effective pollinators? *Ecology Letters* **17**: 388-400.

Sargent, O.H. 1928: Reactions between birds and plants. *Emu – Austral Ornithology* **27**: 185–192.

Sedgley, M. & Griffin, A.R. 1989: *Sexual Reproduction of Tree Crops*, Academic Press, London: 378 pp.

Sedgley, M. & Harbard, J.L. 1993: Pollen storage and breeding system in relation to controlled pollination of 4 species of Acacia (Leguminosae, Mimosoideae). *Australian Journal of Botany* **41**: 601–609.

Sérsic, A.N. & Cocucci, A. 1996: A remarkable case of ornithophily in *Calceolaria*: food bodies as rewards for a non-nectarivorous bird. *Botanica Acta* **109**: 172–176.

Smart, I. & Knox, R. 1979: Aerobiology of grass pollen in the city atmosphere of Melbourne: quantitative analysis of seasonal and diurnal changes. *Australian Journal of Botany* **27**: 317–331.

Stone, G.N., Raine, N.E., Prescott, M. & Willmer, P.G. 2003: Pollination ecology of Acacias (Fabaceae, Mimosoideae). *Australian Systematic Botany* **16**: 103–118.

Tullis, K., Calver, M. & Wooller, R. 1982: The invertebrate diets of small birds in Banksia woodland near Perth, W.A., during winter. *Wildlife Research* **9**: 303–309.

Vanstone, V.A. & Paton, D.C. 1988: Extrafloral nectaries and pollination of *Acacia pycnantha* Benth. by birds. *Australian Journal of Botany* **36**: 519–531.

Wandrag, E.M., Sheppard, A.W., Duncan, R.P. & Hulme, P.E. 2015: Pollinators and predators at home and away: do they determine invasion success for Australian *Acacia* in New Zealand? *Journal of Biogeography* **42**: 619–629.

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APPENDIX 1

Invertebrate survey data from branch beating and observation on four flowering trees and one non-flowering tree.[1] Total numbers across all trees and seven observation dates.

Class	Order	Family	Common name	State	Invertebrates BEATING (non-flowering tree)	Invertebrates BEATING (flowering)	Invertebrates OBSERVED (flowering)	Total (flowering trees only)
Insecta	Blattodea	Ectobiidae	Cockroach	Adult	0	2	0	2
Insecta	Coleoptera	Attelabidae	Leaf rolling weevils	Adult	0	2	0	2
Insecta	Coleoptera	Cerambycidae	Longicorns	Adult	0	0	1	1
Insecta	Coleoptera	Chrysomelidae	Leaf beetles	Adult/ Larvae	2	61	6	67
Insecta	Coleoptera	Cleridae	Clerid beetles	Adult	0	2	0	2
Insecta	Coleoptera	Coccinellidae	Ladybirds	Adult	0	23	1	24
Insecta	Coleoptera	Curculionidae	Weevils	Adult	0	0	1	1
Insecta	Coleoptera	Latridiidae	Minute scavenger beetle	Adult	0	30	0	30
Insecta	Coleoptera	Nitidulidae	Sap beetles	Adult	0	3	0	3
Insecta	Coleoptera	Scarabaeidae	Scarab beetles	Adult	0	0	7	7
Insecta	Coleoptera	Tenebrionidae	Darkling beetles	Adult	0	1	0	1
Insecta	Diptera	cf. Anthomyiidae	Root maggot flies	Adult	0	0	1	1
Insecta	Diptera	Cecidomyiidae	Gall midges	Adult	0	9	0	9
Insecta	Diptera	Chironomidae	Midges	Adult	0	106	19	125
Insecta	Diptera	Chloropidae	Frit flies	Adult	0	9	0	9
Insecta	Diptera	Empididae	Dance flies	Adult	0	5	0	5
Insecta	Diptera	Lauxaniidae	Lauxaniid flies	Adult	0	0	1	1
Insecta	Diptera	Phoridae	Scuttle flies	Adult	1	3	0	3
Insecta	Diptera	Sciaridae	Fungus gnats	Adult	0	15	1	16
Insecta	Diptera	Syrphidae	Hoverflies	Adult	0	7	31	38
Insecta	Diptera	Tachinidae	Tachinid flies	Adult	0	0	3	3
Insecta	Diptera	*Diptera Unknown*		Adult	0	8	0	8
Insecta	Hemiptera	cf. Callipappidae	Bird of paradise flies	Adult	0	0	1	1
Insecta	Hemiptera	Cicadellidae	Leafhoppers	Adult/ nymph	3	7	0	7
Insecta	Hemiptera	Miridae	Plant bugs	Adult/ nymph	1	75	1	76
Insecta	Hemiptera	Monophlebidae	Giant scales	Adult	0	0	1	1
Insecta	Hemiptera	Pentatomidae	Shield bugs	Adult	0	0	1	1
Insecta	Hemiptera	Pseudococcidae	Mealy bugs	Adult	0	3	0	3
Insecta	Hemiptera	Psyllidae	Psyllids	Adult/ nymph	16	74	0	74
Insecta	Hemiptera	Reduviidae	Assasin bugs	Adult	0	1	0	1
Insecta	Hemiptera	Tingidae	Lace bugs	Adult	0	9	0	9

Class	Order	Family	Common name	State	Invertebrates BEATING (non-flowering tree)	Invertebrates BEATING (flowering)	Invertebrates OBSERVED (flowering)	Total (flowering trees only)
Insecta	Hymenoptera	Apidae	Bees	Adult	0	0	21	21
Insecta	Hymenoptera	Bethylidae	Aculeate wasps	Adult	0	2	0	2
Insecta	Hymenoptera	Braconidae	Braconid wasps	Adult	0	5	2	7
Insecta	Hymenoptera	Colletidae	Short-tongued bees	Adult	0	1	2	3
Insecta	Hymenoptera	Diapriidae	Parasitoid wasps	Adult	1	1	0	1
Insecta	Hymenoptera	Encyrtidae	Parasitoid wasps	Adult	1	7	0	7
Insecta	Hymenoptera	Eulophidae	Parasitoid wasps	Adult	0	12	1	13
Insecta	Hymenoptera	Formicidae	Ants	Adult	1	11	2	13
Insecta	Hymenoptera	Halictidae	Burrowing bees	Adult	0	0	6	6
Insecta	Hymenoptera	Ichneumonidae	Ichneumon wasps	Adult	0	0	11	11
Insecta	Hymenoptera	Platygastridae	Parasitoid wasps	Adult	1	146	1	147
Insecta	Hymenoptera	Pteromalidae	Parasitoid wasps	Adult	1	9	0	9
Insecta	Hymenoptera	Tiphiidae	Flower wasps	Adult	0	0	2	2
Insecta	Hymenoptera	*Hymenoptera Unknown*		Adult	0	6	7	13
Insecta	Lepidoptera	Geometridae	Loopers	Larvae	0	1	0	1
Insecta	Lepidoptera	Lymantriidae	Tussock moths	Larvae	0	1	2	3
Insecta	Lepidoptera	Oecophoridae	Concealer moths	Adult	0	1	0	1
Insecta	Lepidoptera	*Lepidoptera Unknown*		Larvae	0	4	0	4
Insecta	Neuroptera	Chrysopidae	Green lacewing	Larvae	0	1	0	1
Insecta	Neuroptera	Coniopterygidae	Dusty wings	Adults	0	18	1	19
Insecta	Neuroptera	Hemerobiidae	Brown lacewings	Larvae	0	3	0	3
Insecta	Thysanoptera	*Thysanoptera Unknown*	Thrips	Adult	0	8	1	9
Araneae		Araneidae	Orb weavers	Adult/ spiderlings	0	1	0	1
Araneae		Clubionidae	Sac spiders	Adult/ spiderlings	0	2	0	2
Araneae		Salticidae	Jumping spiders	Adult/ spiderlings	0	1	0	1
Araneae		Theridiidae	Comb-footed spiders	Adult/ spiderlings	0	33	0	33
Araneae		Thomisidae	Crab spiders	Adult/ spiderlings	0	46	1	47
Araneae		*Araneae Unknown*		Adult/ spiderlings	2	7	0	7
Acari		Unknown	Mites		2	14	0	14

[1] For photographic records of most taxa by K. Ellison see: https://www.flickr.com/photos/zosterops/albums/72157698885625455/page1

APPENDIX 2

Daily records of bird species observed visiting *A. dealbata* crowns over a 10-minute observation period at each of five observation points at Knocklofty (Site 1). Ambient conditions and flowering status of observed trees are shown for each observation point.

Obs. point	Bird species and flowering	Days from start (26 June)																
		1	6	14	21	28	34	40	43	49	57	61	65	70	77	87	92	95
1	Brown Thornbill	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Yellow Wattlebird	–	–	–	–	–	–	1	–	–	–	–	–	–	2	–	–	–
	Yellow-throated Honeyeater	1	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–
	Other	2	–	–	1	–	–	–	1	1	–	–	–	–	–	–	–	–
	Flowering (% receptive)	0	0	0	0	0	0	2	5	20	70	90	90	20	10	0	0	0
2	Brown Thornbill	–	–	–	–	–	–	–	–	–	–	2	2	–	–	–	–	–
	Green Rosella	–	–	–	–	–	–	6	–	4	–	–	–	–	–	–	–	–
	Yellow Wattlebird	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
	Other	1	1	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–
	Flowering (% receptive)	0	0	0	0	0	1	2	2	15	20	50	70	80	20	2	0	0
3	Brown Thornbill	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–
	Green Rosella	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
	Yellow-throated Honeyeater	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
	Other	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
	Flowering (% receptive)	0	0	0	1	20	30	80	100	50	50	10	10	10	10	0	0	0
4	Brown Thornbill	1	–	–	–	–	–	3	–	–	2	–	3	–	–	–	1	–
	Green Rosella	–	–	–	–	–	–	–	3	1	–	–	–	–	–	–		–
	Yellow Wattlebird	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–
	Yellow-throated Honeyeater	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Other	1	1	–	–	–	1	–	–	–	2	–	–	2	–	–	–	–
	Flowering (% receptive)	0	0	1	1	5	10	25	80	45	80	70	70	75	50	0	0	0
5	Brown Thornbill	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
	Other	3	–	–	1	1	–	–	–	–	–	–	1	–	–	–	–	–
	Flowering (% receptive)	0	0	0	0	0	0	1	2	20	30	30	30	40	60	5	5	5
Ambient temperature (°C)		10	10	7	12	11	12	10	10	14	10	9	12	13	18	15	12	12
Wind speed (terrestrial Beaufort scale)		1	5	3	5	5	4	5	5	4	4	4	3	2	4	4	4	4
Sunlight (S full, P partial)		S	S	S	S	S	S	S	S	S	S	S	S	P	P	P	S	S
Current moisture (D dry, W wet)		D	D	D	D	D	D	D	W	D	D	D	D	D	D	D	D	D

THE TOURIST AND TOURISM GAZES UPON CRADLE MOUNTAIN AND FREYCINET NATIONAL PARK

by Chantelle Ridley

(with four text-figures and four tables)

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The natural aesthetic resource is an important element of natural and cultural heritage and an attractor of tourists. It is important for heritage management to understand the scenic attractors of tourists. Photographs of Cradle Mountain (150) and Freycinet National Park (149) were collected from a range of sources to determine whether there is a constancy of gaze between those who promote tourism and those who tour, and between the two visually distinct destinations. Publicly available images from four different sources were used to compare content attributes and mise en scène attributes between localities using Chi-square and ANOSIM. The photographs were then ordinated using the same attributes, and the results were displayed using photographic average composites. The Discover Tasmania and Google Images photographs were similar, both better conforming to advanced compositional principles compared to the Instagram and promotional images, which were similar, especially in the featuring of people in landscape foregrounds. There may be a reciprocal interaction between promotional and tourist images, rather than a one-way process. The contrasting features in the images from the two places were largely a product of the very different physical environments. However, the photographs at Freycinet were taken from several geographic locations, whereas the vista of Dove Lake and Cradle Mountain dominated all image sources at Cradle Mountain. The content analysis of the images was consistent between places, except where a feature of an artefact or natural feature created opportunity for artistic expression.
Key Words: aesthetic resource, content analysis, Discover Tasmania, Google Images, Instagram, mise en scène, images, promotional images.

INTRODUCTION

> *"Nature was tamed, put into perspective with, and by, the human eye, as a landscape picture, a single vision of order."* (Urry & Larson 2011, p. 131)

Wilderness landscapes, once terrifying and depressing, are now places for pleasure, solitude and contemplation (Schirpke *et al.* 2013). Natural aesthetic resources that tend towards the sublime (Beza 2010, Kirillova *et al.* 2014) are an intangible asset in protected areas (Mendel & Kirkpatrick 1999) as they attract tourists, and therefore economic development.

In 2019, most tourists have the technological means to immediately and globally communicate their arrival at a tourist icon through social media via image and hashtagged caption. The presence of tourists at scenic icons may be motivated by the images of previous visitors, or by the images presented by professional agents. These sources indicate destinations in which tourists can view the extraordinary (Stylianou-Lambert 2012). Phelps (1986) classifies promotional images as secondary images and images generated by tourists as primary. Tourists are regarded as passive consumers of scenes by replicating the images they see in promotional material; or as active participants, recreating scenes through the lens of their own experiences (Stylianou-Lambert 2012). The latter perspective may be particularly apposite to social networking sites, such as Instagram.

There are few published comparisons between primary and secondary images (Stephchenkova & Zhan 2013, Paül i Agustí 2018). Sources are usually treated independently and are examined through the lens of a single discipline (Stylianou-Lambert 2012). It is important to examine primary and secondary sources though a multidisciplinary lens, to extend our understanding of tourist behaviour and perception. One widely used method to quantify visual preferences for landscapes is content analysis (Linton 1968, Wang *et al.* 2016, Tieskens *et al.* 2018, Pickering *et al.* 2020). Content analysis examines landscape elements within an image, such as quality and quantity of vegetation, distance to vegetation, water bodies (Shafer & Brush 1977, Patsfall *et al.* 1984) and mountains (Mendel & Kirkpatrick 1999).

Integrating content analysis with mise en scène techniques may reveal hidden relationships previously not studied in destination imagery. Mise en scène, or 'to appear on stage' is a traditional theatrical technique used to convey narrative and mood, via composition, lighting, setting and clothing (Giannetti 2014). This same technique is applied cinematically and photographically, within a frame. Preferences for, and perceptions of, desirable landscapes are influenced by position on the continuum from realistic to abstract representation in destination images (Daniel & Meitner 2001).

The social media component of the study was conducted using the smartphone image-sharing platform 'Instagram', which allows users to share images publicly or privately.

Instagram was chosen because of its popularity in the current social climate (Choi & Sung 2018) and its use in recent studies on its application by tourists (University of Tasmania 2019). However, using Instagram has limitations as the samples include only images from accounts that have been made publicly accessible. Images are in Instagram using keywords that relate to either a title (user), geotag (location) or a hashtag (category). Location can easily and automatically be applied to an image if the GPS services are activated on the device. Hashtags are used to categorise the image to reach niche demographics.

Data visualisation is the transformation of quantitative or qualitative data into graphic representation. When large and complicated data sets are transformed into aesthetic graphics, information becomes accessible, comparable and better understood among general audiences (Felton *et al.* 2016).

Photographic averaging composites are a post processing method that aligns and blends photographs together (Felton *et al.* 2016). This method has been widely used to illustrate specific collectives, such as in portraiture to find the average face and the similarity of photographs taken of tourism icons (Felton *et al.* 2016, Bergh *et al.* 2018).

In this study the contents and mise en scène of images were compared to determine whether there is a constancy of gaze between those who promote tourism and those who tour, and between two visually distinct destinations. I determined whether contents and artistic designs differ between images collected from four distinct sources: printed promotional material (i.e., tourism brochures), Discover Tasmania Instagram site (henceforth Discover Tasmania), Google Images and Instagram. I used the two most iconic national park destinations in Tasmania: Freycinet and Cradle Mountain. Photographic average composites illustrate the differences between sources.

METHODS

The study area

Tasmania (41.640079°S, 146.315918°E) is an island state of Australia, located 240 km south of the mainland (fig. 1). Tasmania has a population of 529,903 (Australian Bureau of Statistics 2018) in a total area of 68,401 km² (Geoscience Australia 2020). The rich and distinctive geodiversity and biodiversity of the island result in natural landscapes of great beauty. Tasmania has 42% (2.9 million ha) of its land dedicated to national parks and reserves (Tasmania Parks & Wildlife Service 2020) with 1.58 million ha of this in the Tasmanian Wilderness World Heritage Area, declared for both cultural and natural values (DPIPWE 2016). Tourism campaigns promote natural features, gourmet produce, wildlife and the arts (Tourism Tasmania 2016). Before the impact of the Covid-19 pandemic, tourism directly and indirectly contributed $3.03 billion (10.4%) to Tasmania's Gross State Product (Tourism Tasmania 2019a). In 2017–2018, 1.32 million people visited the state with 307,000 international visitors and 1.09 million arriving from interstate (Tourism Tasmania 2019a, b). International and interstate tourists on holiday are more likely to visit a national park than those visiting Tasmania for business activities or to visit friends and relatives (Tasmania Parks & Wildlife Service 2019).

FIG. 1 — The island state of Tasmania showing the study areas of Freycinet National Park and Cradle Mountain-Lake St Clair National Park.

Site selection

Two popular, and environmentally different, tourism icons were chosen for the study (fig. 1). The coastal Freycinet National Park has the highest number of visitors of any national park in the State (Tasmania Parks & Wildlife Service 2019). The subalpine/montane Cradle Mountain, located to the west, is the second most visited location in the national park estate (Tasmania Parks & Wildlife Service 2019).

Selection of images

Images were selected if they satisfied the following criteria:

- images were taken within the park boundary and viewpoints were accessible without overnight camping;
- images were of landscapes.

Images were collected from tourist information brochures, social media and the web using the Google Images search engine. All images were collected in the 2018–2019 summer peak tourism season. All data were manually retrieved.

Printed promotional material was used to obtain the images that private companies used to attract customers. This material consisted of brochures advertising accommodation and private tours. Printed promotional material was collected from three tourist information centres in Tasmania in February 2019. All images from the study areas were used.

A Google Images search on the web was conducted using variants of the locality names. The keywords 'Freycinet'

and 'Cradle Mountain' received the highest number of images. It was assumed that images that first appeared in the search would be more likely to represent professional material, as advanced development of their website/image allowed the image to be there in the first place. Images were sampled sequentially from the first image.

For Instagram (i.e., a photo and video sharing social networking service owned by Facebook), it was decided that location was to be used to select images as more images per day were uploaded using location than those hashtagged. Images were selected from 'Freycinet National Park' and 'Cradle Mountain', between 1 October 2018 and 31 March 2019, using a random number generator.

Tourism Tasmania's Official Instagram account 'Discover Tasmania' (https://www.instagram.com/tasmania/) was used to represent destination images promoted by the State Government. 'Discover Tasmania' is created through user-generated content where hashtagging #discovertasmania or #tassiestyle, gives permission for the organisation to use the image in online promotions.

Two hundred and ninety-nine images were sampled (table 1). All were freely available to the public. One hundred images were from promotional/professional sources, 100 from recreational and 99 from a professional source using recreational user-generated images. A running mean for the presence of water in randomly selected images from the selection was calculated. The presence of water in an image equalled one and its absence zero. This mean stabilised at around 25 images. The process was repeated with mountains, with the same outcome.

Content analysis – location and subjects

The most popular viewpoints for each media type at Cradle and Freycinet were determined using the author's knowledge of the areas. Local knowledge was required to assess the location of the image. Location was coded as marine, if it was taken on the water, and by the nearest geographical feature if terrestrial. When available, captions and hashtags were used to cross-validate these data. The percentage of images taken at each geographical location in each national park was calculated to determine which were the most popular sites to photograph across all media sources and within and between national parks (fig. 2a and 2b).

The presence/absence of landscape elements were recorded. These were: water bodies, mountains and vegetation as a feature (e.g., tree trunks, shrubbery, cushion plant). The measurement method of Oktas was used to determine cloud cover and as an estimate of the weather conditions: clear: 0–10%, scattered: 10–50%, broken: 50–90%, overcast: 90–100%. Artefacts included monuments (lighthouse, shed, accommodation, hut), infrastructure (boardwalk, trail, railing, sign), transportation (boat, car, plane, kayak, paddleboard), natural features (rock, geology, driftwood, milky way), weather phenomena (snow, mirrored reflections on still water), animals and toys.

Mise en scène criteria

The mise en scène component of lighting, conveying mood, tone and focus within the frame was captured in six time-of-day categories (sunrise, early morning, day, late afternoon, sunset, night). Shot and camera proxemics describe how much of the subject is in the frame and how much of the human subject is within the frame. Each image was classified as either terrestrial, marine or aerial. The nature of the composition of the image was recorded for each of: the rule of thirds in which the subject matter is organised in nine equal rectangles, with important details placed off centre where the lines intersect; the use of the golden rule; the use of geometric features in the image; the use of features as leading lines; central location; and, split design in which there is symmetry in the image. Three characteristic depths of field were recorded.

Data analysis

Chi-squared was used for individual class variables to determine whether there was deviation from random in data related to source (promotional, Instagram, Discover Tasmania and Google Images) or location (Freycinet, Cradle Mountain). Pearson's Method was used to determine the p value. These analyses were done in Minitab18.

Non-metric multidimensional scaling was used to ordinate the images using the qualitative (1/0) content and mise en scène variables listed above. The default options in DECODA were used for this process. An ANOSIM analysis of differences between the combination of places and sources was undertaken in DECODA using the scores on the four dimensions of the ordination with the use of 10,000 permutations to calculate the probabilities associated with the R statistic. In all analyses the null hypothesis was rejected if $p < 0.05$.

TABLE 1 — The most photographed locales at Cradle Mountain and Freycinet National Park by source, showing the number of images for the source by locality.

Image source	Freycinet National Park		Cradle Mountain	
	No.	Most Frequent	No.	Most Frequent
Promotional	7/22	Wineglass Lookout	6/23	Dove Lake
Google Images	9/28	Freycinet Peninsula	5/27	Dove Lake
Instagram	11/50	Wineglass Lookout	8/50	Dove Lake
Discover Tasmania	10/49	Mount Amos	11/50	Dove Lake

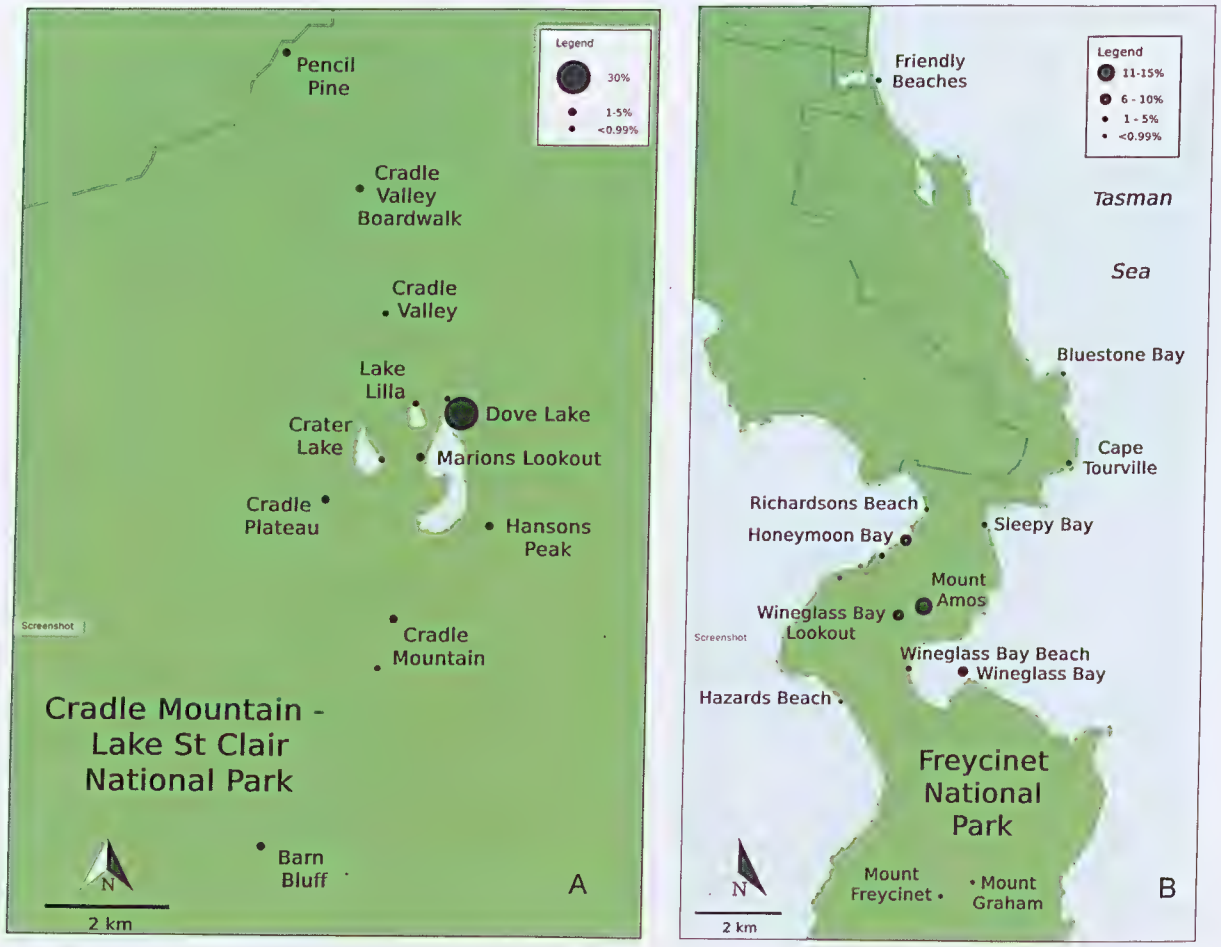

FIG. 2 — Percentage of images taken at geographical locations across all media sources at (**A**) Cradle Mountain and (**B**) Freycinet, Tasmania.

Creation of photographic average composites

The photographic average composites (PAC) were based on the significant results derived from the mise en scène and content analysis. The process was applied to one or a few locales with the highest frequency of images. The iconic landscape value informed the centre point. Having this visual anchor creates greater harmony in the PAC and a pivot for the remaining scene to play out.

To construct the PAC, landscape long shot images of the most photographed locale were selected from each source type. Printed promotional material was not used to construct a PAC as it required digitisation and there was excess visual noise with the graphic design.

Images were not resized so as to retain the quality of the information. PAC were constructed on a large blank project and were not cropped in the final presentation. This was both an aesthetic and data integrity decision, as the final presentation revealed information about the original orientation of the images. The one exception to this rule were the Google Images shots of Freycinet. These images were aerial and therefore did not have an optimal viewpoint or consistency in landscape shot types. Due to a low number of images, all shot types had to be utilised. The decision to resize the images was based on aesthetics, as the alterations created a more visually harmonious PAC. Images that are closest to the front of the stack provide the details (Felton *et al.* 2016).

RESULTS

Freycinet had a higher number of locales photographed compared to Cradle Mountain (table 1, fig. 2). Thirty percent of the 299 images that were photographed were at Dove Lake below Cradle Mountain, followed by Mount Amos (14%), Wineglass Bay Lookout (8%) and Honeymoon Bay (6.4%) all at Freycinet. The most photographed locale was constant between sources for Cradle Mountain (table 1).

The stress for the four-dimensional ordination was 0.163. The overall ANOSIM R value for the differentiation by source and place was 0.0276 (p = 0.012). There was significant differentiation between all combinations of place and medium with Discover Tasmania and Instagram images (table 2). There was also significant differentiation between all combinations of place and medium with promotional images and Google Images (table 2). Thus, Discover Tasmania images were similar to Google and promotional images. Instagram images were also similar to Google and promotional images. Promotional images and Google Images shots were similar to Discover Tasmania and Instagram images (table 2).

TABLE 2 — Combinations of place and source that were significantly different on the four-dimensional ordination scores for all qualitative variables (ANOSIM R-statistic).

	DF	DC	IF	IC	PF	PC	GF	GC
DF	X	*	*	***	-	-	-	-
DC	*	X	*	***	-	-	-	-
IF	*	*	X	*	-	-	-	-
IC	***	***	*	X	-	-	-	-
PF	-	-	-	-	X	*	**	***
PC	-	-	-	-	*	X	**	*
GF	-	-	-	-	**	**	X	**
GC	-	-	-	-	***	*	**	X

*** = $p < 0.001$, ** = $p < 0.01$, * = $p =/< 0.05$, - = $p > 0.05$. X marks no results as self-comparison. DF = Discovery Tasmania/Freycinet, DC = Discovery Tasmania/Cradle, IF = Instagram/Freycinet, IC = Instagram/Cradle, PF = Promotional/Freycinet, PC = Promotional/Cradle, GF = Google/Freycinet, GC = Google/Cradle.

TABLE 3 — The percentage frequency of content and mise en scène variables by source for those that vary significantly (Chi-squared).

Variable	Discover Tasmania	Google Images	Instagram	Promotional	P-Value
Extended long shot	14	**29** [1]	6	20	<0.001
Geometry	**34**	20	22	4	<0.001
Thirds	17	51	32	**76**	<0.001
Terrestrial	88	82	95	**98**	0.012
Water	82	**98**	89	82	0.020
Mountains	88	87	68	**89**	0.001
Day	44	80	86	**93**	<0.001
Very wide shot figure	33	11	16	**38**	<0.001

[1] The higher percentage is shown in bold.

TABLE 4 — The percentage frequency of content and mise en scène variables by place for those that varied significantly (Chi-squared).

Variable	Cradle	Freycinet	P-Value
Geometry	17	**29** [1]	0.018
Split	**12**	5	0.023
Terrestrial	**100**	81	<0.001
Aerial	0	**13**	<0.001
Water	78	**97**	<0.001
Mountains	**86**	77	0.035
Scattered clouds	26	**42**	0.003
Broken clouds	**25**	15	0.046
Landscape vegetation	92	**97**	0.041
Feature vegetation	**16**	7	0.011
Medium close-up figures	**11**	3	0.006
Boardwalk	**12**	5	0.023
Rock	13	**23**	0.015
Reflection	**7**	0	0.001

[1] The higher percentage is shown in bold.

FIG. 3 — Photographic average composites (PAC) of Dove Lake, Cradle Mountain, Tasmania. PAC were created from the overlay of multiple images sourced from (A) Discover Tasmania; (B) Instagram; and (C) Google Images search.

The Discover Tasmania images had the highest percentages of geometric design (table 3). The Google Images shots had the highest percentages of extended long landscape shots and the greatest proportion of presence of water (table 3). The promotional images had the highest proportions of composition by thirds, terrestrial scenes, mountains, daytime shots and very wide shot figures (table 3).

Most of the differences between the images taken at Cradle Mountain and those at Freycinet reflected differences in their physical environment, some possible exceptions being more medium close-up figures and split images at Cradle Mountain and more aerial shots and use of geometric composition at Freycinet (table 4).

The PACs of Cradle Mountain differed in the contrast between dawn and dusk skies in the Discover Tasmania images (fig. 3A), compared to clear daytime skies in the Google (fig. 3C) and Instagram images (fig. 3B), and the wider frame and greater complexity of the Google PAC compared to the others. At Freycinet, the most popular Discover Tasmania image was from Mt Amos, with Wineglass Bay sitting like a lake below, framed by mountains (fig. 4A). The most popular Instagram image was from the Wineglass Bay lookout (fig. 4B). The most popular Google Image was of Wineglass Bay from the south (fig. 4C).

DISCUSSION

This study highlights the complex feedbacks between promotional/ professional images and tourist images. The current rise in user-generated content for advertising (or 'influencing' as it has been repackaged) through social media, has added complexity into image sources and their feedbacks beyond the simple influence model (Stephchenkova & Zhan 2013).

It was expected that Google Image shots and promotional material would represent the professional aspect of the study, and Instagram and Discover Tasmania would represent the perceptions of the tourist. However, the images from Discover Tasmania were very similar to professional material and promotional images. Despite Discover Tasmania images being sourced from Instagram, the former had a closer relationship to the artistic Google Images than

FIG. 4 — Photographic average composites (PAC) of (**A**) Mount Amos; (**B**) Wineglass Bay lookout; and (**C**) Freycinet Peninsula at Freycinet National Park, Tasmania. PAC were created from the overlay of multiple images sourced from (A) Discover Tasmania; (B) Instagram; and (C) Google Images searches.

to those in the Instagram pool. As Instagram were more related to Google Images and promotional material, it is likely that the images from the Instagram pool were those that conformed to mise en scène principles and a particular aesthetic related to time of day. Google Images and promotional material were related to Instagram and Discover Tasmania, emphasising that there is a complicated feedback process between image sources.

While tourists may be influenced to seek the reality of an image, they may not necessarily be able to seek the optimal photographic timing (Stylianou-Lambert 2012). because of a short visit or a lack of compositional skills. The Discover Tasmania PAC of Cradle Mountain is reminiscent of paintings from the Romantic period containing uncultivated and undeveloped landscape, mood lighting, warm hues and figures dwarfed by the landscape (fig. 3a). The romantic gaze symbolises solitude and undisturbed natural beauty (Urry 2005, Pan *et al.* 2014). Tourism images have been also been found to prefer warmer hues (Yu *et al.* 2020).

The high degree of similarity of promotional material to Instagram shots may indicate that the creators of the material have a strong understanding of tourist preferences or that images used in promotions were created by tourists. User-generated content is believed to have high authenticity, and therefore more likely to induce feelings and behaviours generated by emotions such as envy and desire than more professional work (Hajli *et al.* 2018). Tourists, therefore, may be both the consumer and the producer (Stylianou-Lambert 2012).

Previous studies have highlighted that the perception of beauty is influenced by social and cultural climate (Urry & Larsen 2011). Natural features, artefacts and photographic technique were largely constant between the two tourist icons, suggesting a constancy of society and culture. Natural features such as vegetation and mountains in this study were depicted using geometric shape and symmetry. Natural features such as the curvature of a beach and the mirrored reflection of a lake provided a strong base for composition.

Tourists desire the unspoilt and remote (Stylianou-Lambert 2012), preferably containing relative relief and water (Mendel & Kirkpatrick 1999). Indicators of development are often omitted (Stylianou-Lambert 2012). However, I sampled images that were taken by tourists that featured artefacts. Artefacts, such as wooden boardwalks, when snaking off into the distance or between trees, can have aesthetic appeal. The information from tourist images can help architects design artefacts that are less obtrusive, or even attractive, in a landscape.

Discover Tasmania had a high incidence in traditional landscape techniques of advanced composition and conscious timing of day for optimal lighting. As they are mise en scène elements, it could be inferred that Discover Tasmania was biased towards 'mood' images, which is reinforced by the PAC. The aquamarine water and white sand beaches highlighted in the PAC reveal that colour, hue, brightness and saturation is a mise en scène element that is worth consideration in future studies (Yu *et al.* 2020).

Google Image's advanced landscape camera shots, perspective and inclusion of artefacts and landscape elements, reflects advanced photographic equipment and technique. The traditional photographic landscape technique is further reflected in the homogeneity of landscape orientation in the PAC. The mise en scène in the Google Images shots contrasts with Discover Tasmania in offering a new perspective and enhanced landscape detail. Although time of day did not differ between Freycinet and Cradle Mountain, visual analysis of the PAC reveals that the average time of day was early in the morning when light was still of photographic quality. Landscapes that contained mountains and water, were more desirable than the exclusive framing of a mountain or water (Smrekar *et al.* 2016), while beaches that are deserted and pristine are highly desirable (Stylianou-Lambert 2012). The rustic shed at Dove Lake adds further appeal, like water, by softening the sharpness of the mountain.

Promotional material was similar to Google Images shots in relation to perspective and landscape elements. Mountains were found to be of high incidence; however, the limitation of this finding is that, at Cradle Mountain, the mountain is of iconic landscape value, whereas the mountain range at Freycinet serves more as a backdrop to the iconic landscape value of Wineglass Bay.

Instagram contrasted with Google Images, promotional material and Discover Tasmania in that the content was centralised around a human figure in the landscape. A mid shot places emphasis on the figure while keeping the background visible. The tourist gaze produces images that allow one to be seen in the desirable location (Hajli *et al.* 2018). It is striking that the PAC are very similar in visual appearance between Freycinet and Cradle Mountain. The images are clustered together, suggesting that the majority are taken from a similar viewpoint; the overall colour of the images is similar as majority of images are taken during the day and adhere to the traditional landscape format. The PAC reaffirm the aforementioned notion that tourists travel to see the iconic landscape value irrespective of the time of day. Image conventions are passed on through advertising and promotional material, influencing the tourist gaze (Stylianou-Lambert 2012). As an example, the Instagram and Google PAC bear strong a similarity in framing, orientation and content. It could also be argued that these visual conventions were established in painting, decades before the invention of photography (Urry & Larsen 2011).

An unexpected finding of this present study, revealed by the PAC, was the influence of photographic equipment on the tourist gaze. This effect is most clearly illustrated in the Cradle Mountain PACs which successively shorten in scene down the cascade of technical ability from Google Images, to Discover Tasmania to Instagram. When comparing the Cradle Mountain and Freycinet Instagram PACs, it is striking that they bear such a strong resemblance.

Visualisation of data through the PAC technique is a new method to validate content and mise en scène analysis. It is an exciting way to reveal patterns and relationships previously not considered and to visualise data sets for science communication.

REFERENCES

Australian Bureau of Statistics 2018: *Australian Demographic Statistics*. Canberra: Australian Bureau of Statistics. https://www.abs.gov.au/ausstats/abs@.nsf/lookup/3101.0Media%20Release1Dec%202018.

Bergh, R., Eyck, G., Eijck, G. & Naafs, S. 2018: *To Infinity and Beyond*. Breda: The Eriskay Connection, Amsterdam: 232 pp.

Beza, B. 2010: The aesthetic value of a mountain landscape: a study of the Mt. Everest Trek. *Landscape and Urban Planning* **97**: 306–317.

Choi, T. & Sung, Y. 2018: Instagram versus Snapchat: Self-expression and privacy concern on social media. *Telematics and Informatics* **35(8)**: 2289–2298.

Daniel, T. & Meitner, M. 2001: Representational validity of landscape visualizations: The effects of graphical realism on perceived scenic beauty of forest vistas. *Journal of Environmental Psychology* **21**: 61–72.

DPIPWE 2016: Tasmanian Wilderness World Heritage Area Management Plan 2016, Department of Primary Industries, Parks, Water and Environment, Hobart: 240 pp

Felton, N., Ehmann, S. & Klanten, R. 2016: *Photoviz*. Gestalten, Berlin: 256 pp.

Geoscience Australia 2020: *Area Of Australia - States And Territories,* https://www.ga.gov.au/scientific-topics/national-location-information/dimensions/area-of-australia-states-and-territories (accessed 20 September 2020).

Giannetti, L. 2014. *Understanding Movies*. 13th edn. Pearson Education Inc., London: 550 pp.

Hajli, N., Wang, Y. & Tajvidi, M. 2018: Travel envy on social networking sites. *Annals of Tourism Research* **73**: 184–189.

Kirillova, K., Fu, X., Lehto, X. & Cai, L. 2014: What makes a destination beautiful? Dimensions of tourist aesthetic judgment. *Tourism Management* **42**: 282–293.

Linton, D. 1968: The assessment of scenery as a natural resource. *Scottish Geographical Magazine* **84**: 219–238.

Mendel, L. & Kirkpatrick, J.B. 1999: Assessing temporal changes in the reservation of the natural aesthetic resource using pictorial content analysis and a grid-based scoring system – the example of Tasmania, Australia. *Landscape and Urban Planning* **43**: 181–190.

Pan, S., Lee, J. & Tsai, H. 2014: Travel photos: Motivations, image dimensions, and affective qualities of places. *Tourism Management* **40**: 59–69.

Patsfall, M., Feimer, N., Buhyoff, G. & Wellman, J. 1984: The prediction of scenic beauty from landscape content and composition. *Journal of Environmental Psychology* **4**: 7–26.

Paül i Agustí, D. 2018: Characterizing the location of tourist images in cities. Differences in user-generated images (Instagram), official tourist brochures and travel guides. *Annals of Tourism Research* **73**: 103–115.

Phelps, A. 1986: Holiday destination image - the problem of assessment. *Tourism Management* **8**: 168–180.

Pickering, C., Chelsey, W.S., Barros, A. & Rossic, S.D. 2020: Using social media images and text to examine how tourists view and value the highest mountain in Australia. *Journal of Outdoor Recreation and Tourism* **29**: 1–12.

Schirpke, U., Tasser, E. & Tappeiner, U. 2013: Predicting scenic beauty of mountain regions. *Landscape and Urban Planning* **111**: 1–12.

Shafer, E. & Brush, R. 1977: How to measure preferences for photographs of natural landscapes. *Landscape Planning* **4**: 237–256.

Smrekar, A., Polajnar Horvat, K. & Erhartič, B. 2016: The beauty of landforms. *Acta Geographica Slovenica* **56**: 321–335.

Stephchenkova, S. & Zhan, F. 2013: Visual destination images of Peru: comparative content analysis of DMO and user-generated photography. *Tourism Management* **36:** 590–601.

Stylianou-Lambert, T. 2012: Tourists with cameras. *Annals of Tourism Research* **39**: 1817–1838.

Tasmania Parks & Wildlife Service 2019: *Visitors To Selected Parks & Reserves 2018-2019*, https://parks.tas.gov.au/Documents/Visitors%20to%20selected%20parks%20%26%20reserves%202018-2019.pdf (accessed 20 September 2020).

Tasmania Parks & Wildlife Service 2020: *About the Tasmania Parks and Wildlife Service | Parks & Wildlife Service Tasmania*, https://parks.tas.gov.au/about-us (accessed 19 September 2020).

Tieskens, K., Van Zanten, B., Schulp, C. & Verburg, P. 2018: Aesthetic appreciation of the cultural landscape through social media: an analysis of revealed preference in the Dutch river landscape. *Landscape and Urban Planning* **177**: 128–137.

Tourism Tasmania 2016: *Asia Engagement Marketing Strategy*. Tourism Tasmania, Hobart: 25 pp.

Tourism Tasmania 2019a: *Tourism Fast Facts*. Tourism Tasmania, Hobart: 1 pp.

Tourism Tasmania 2019b: *Tourism Research*. Tourism Tasmania, Hobart. https://www.tourismtasmania.com.au/__data/assets/pdf_file/0008/84635/2019-Q2-Tasmanian-Tourism-Snapshot-June-2019-TVS-IVS-NVS.pdf

University of Tasmania 2019. *Understanding Social Media Use in The Sensing Tourist Travel Study - Tourism Tracer*, https://tourismtracer.com/understanding-social-media-use-in-the-sensing-tourist-travel-study/ (accessed 21 March 2019).

Urry, J. 1995: Consuming Places. Routledge, London: 264 pp.

Urry, J. & Larsen, J. 2011: *The Tourist Gaze 3.0*. SAGE Publications Ltd., London: 282 pp.

Wang, R., Zhao, J. & Liu, Z. 2016: Consensus in visual preferences: The effects of aesthetic quality and landscape types. *Urban Forestry & Urban Greening* **20**: 210–217.

Yu, C., Xie, S. & Wen, J. 2020: Coloring the destination: The role of color psychology on Instagram. *Tourism Management* **80**: 104–110.

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BLACK RATS ERADICATED FROM BIG GREEN ISLAND IN BASS STRAIT, TASMANIA

by Susan Robinson and Wayne Dick

(with four text-figures and four tables)

Robinson, S. & Dick, W. 2020 (9:xii): Black Rats eradicated from Big Green Island in Bass Strait, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 154: 37–45. ISSN: 0080–4703. Biosecurity Tasmania, 13 St Johns Avenue, New Town, Tasmania 7008, Australia (SR*); Tasmania Parks and Wildlife Service, Furneaux Field Centre, 2 Lagoon Road, Whitemark, Tasmania 7255, Australia (WD). *Author for correspondence. Email: sue.robinson@dpipwe.tas.gov.au

Big Green Island is a 129-ha Nature Reserve and part of the Furneaux Group of islands in Bass Strait, southeastern Australia. Beginning in April 2016, Black Rats *Rattus rattus* were targeted for eradication using poisoning with 50 ppm brodifacoum wax blocks via a 25 x 25 m grid of bait stations (16 stations per ha) checked daily for a four-week period followed by three one-week visits over an eight-week period. After six weeks, rodent chew-cards were deployed exposing pockets of rat activity on the island. Island-wide monitoring led to the capture of six rats, the last known rat being killed in November 2016. Monitoring for signs of rats proceeded for a further two years and the island was declared rat-free in November 2018. The project encompassed partnerships between government agencies, industry and non-government organisations, and involved a significant volunteer contribution.

Key Words: island eradication, invasive species, rodent, Black Rat, *Rattus rattus*, brodifacoum, bait station.

INTRODUCTION

In 2006 the Australian Government listed exotic rodents (Black or Ship Rats *Rattus rattus*; Norway or Brown Rats *R. norvegicus*; Pacific Rats *R. exulans*; and House Mouse *Mus musculus*) on islands as a key threatening process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). A threat abatement plan for invasive rats and mice on islands less than 100,000 ha (Commonwealth of Australia 2009) was subsequently developed. The state of Tasmania has over 600 vegetated islands around its coastline, with at least 39 known to have invasive rodents and probably more with unrecorded populations.

Tasmania's first island eradication for rodents (Black Rats) was on Fisher Island (1 ha) in 1974 (Serventy 1977). The next was Macquarie Island (12,800 ha) for Black Rat and House Mouse (plus European Rabbit *Oryctolagus cuniculus*) in 2011 (Springer 2016). Fisher Island again had rodents eradicated in 2013 (House Mouse and Black Rat, S. Robinson unpublished data).

The Tasmanian Parks and Wildlife Service (PWS) identified there would be significant environmental and economic gains in eradicating Black Rats from Big Green Island Nature Reserve (129 ha) in the Furneaux Group, Bass Strait. The two islets immediately north of the main island were considered potential habitats for small species of seabirds (e.g., Fairy Tern *Sterna nereis*, White-faced Storm Petrel *Pelagodroma marina* and Common Diving Petrel *Pelecanoides urinatrix*) which were likely to be prevented from successfully breeding by the presence of rats. The economic gains from eradicating rats were that the cost of ongoing control through baiting by the PWS would no longer be required, and the reduction in pasture seed loss to rats would be a gain for the island's lessee.

The Black Rat has a global distribution and is listed among the worst invasive species in the world (Global Invasive Species Database 2019). They likely arrived in Australia with Dutch ships in the 1600s and fully established with European settlement in the 1780s (Banks & Hughes 2012). Black Rats are generalist omnivores, a trait shared with many successful vertebrate pests. They will eat almost any food up to their own body weight including vegetation, seeds, invertebrates, small vertebrates and the eggs and young of larger vertebrates (Banks & Hughes 2012). The direct impacts of Black Rat on wildlife are not well documented, with much of the evidence recorded through the recovery of native species after rats are eradicated from islands, particularly in New Zealand (Towns *et al.* 2006).

An adult Black Rat weighs up to 225 g and lives about a year. The species has a gestation period of 21 days and weans its young at around 20 days. A female can have 5–10 young per litter and produce up to six litters per year in ideal conditions (Van Dyck & Strahan 2008).

SITE DETAILS

Description

Situated in Bass Strait, 3 km west of Flinders Island, the main island of the Big Green Island group is 125 ha, mostly granite and gently rising to 30 m (fig. 1). The island was intensively managed to provide food for the Aboriginal settlement at Wybalena from the 1830s, including sheep, rabbits, Cape Barren Goose (*Cereopsis novaehollandiae*), Short-tailed Shearwaters (*Ardenna tenuirostris*) and their eggs (Backhouse 1843). The vegetation is now mostly non-native pasture species fringed by a coastal strip of native Tussock Grass (*Austrostipa stipoides*) (Harris *et al.* 2001). There is a patch of succulent herbfield in the north and invasive African Boxthorn (*Lycium ferocissimum*) along the northeastern bay, east coast and scattered across the group

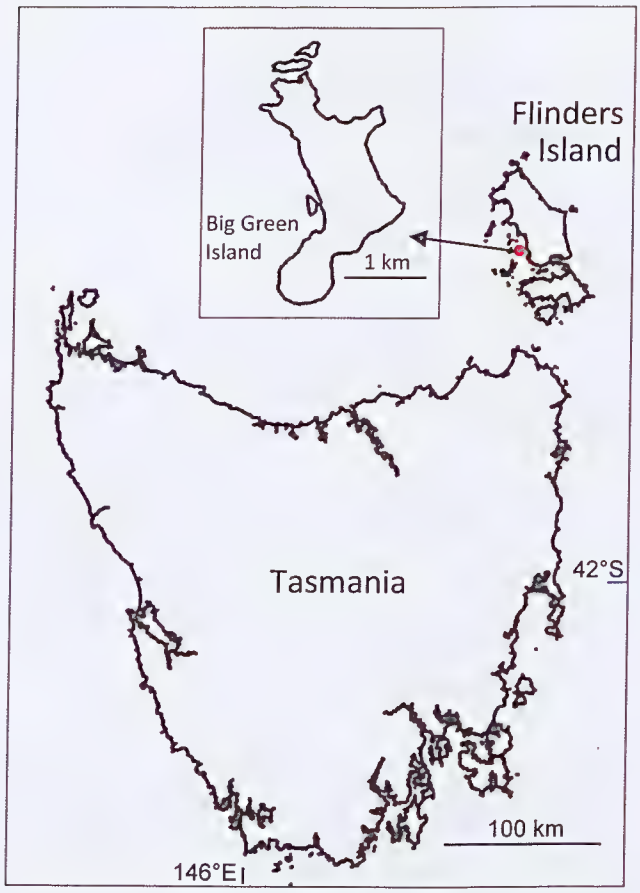

FIG. 1 — Location of Big Green Island relative to Tasmania and Flinders Island.

(Harris *et al.* 2001). The islets to the north, which are joined by a rocky isthmus at low tides, maintain an assemblage of native plant species including Tussock Grass, Saltbush (*Atriplex* sp.) and succulents (*Sclerostegia* sp. shrubs). The main island is fully accessible by foot and the nearby islets require low tides for access.

The freehold island was sold to the PWS in 1980 and declared a Nature Reserve to establish a secure breeding site for Cape Barren Geese which had a declining population at the time. Sheep grazing continued under a lease agreement to maintain the short grass that is favoured by geese. The island has two cottages and a shearing shed that are used by the island's lessee on a regular basis. Access is by boat from Whitemark, Flinders Island, 6 km to the northeast.

An estimated 22,000 pairs of Short-tailed Shearwater and 400 pairs of Little Penguin (*Eudyptula minor*) breed on Big Green Island (Brothers *et al.* 2001). Other breeding seabirds include low numbers of Pacific (*Larus pacificus*) and Silver Gulls (*L. novaehollandiae*), Pied (*Haemotopus longirostris*) and Sooty Oyster-catchers (*H. fuliginosus*), Black-faced Cormorant (*Phalacrocorax fuscescens*), Caspian Tern (*Sterna caspia*) (Brothers *et al.* 2001) and around 26 breeding pairs of Cape Barren Goose (G. Hocking pers. comm.).

It is unknown when rats arrived, but they likely came with the first settlers to the island in the 1830s. European Rabbit were introduced in 1832 (Backhouse 1843) and died out due to drought around 1914 (D. Cooper pers. comm.). House Mouse were reported around buildings on the island between 1965 and 1968 (Norman 1970) but none have been recorded since then. Flinders Island (3 km away) has Black Rat, Brown Rat and House Mouse.

Rodent baiting history

Rodent control has been undertaken on Big Green Island sporadically since 1984 by the current lessee. Rats were a significant problem for pasture regeneration due to the consumption of seed-heads. Purchased seed was spoiled through gnawing of packaging and consumed when newly sown. Rodent baiting with sodium monofluroacetate (i.e. 1080) occurred from 1984. From the initial trials with 1080, a regime of frequent poisoning was developed (two to three times a year) using a gridded network of over 700 bait stations (halved plastic 20-litre sheep drench containers). By 1996 the rat population had increased markedly despite continued poisoning. Brodifacoum baits were used until 2003, followed by flocoumafen in 2004. In 2008, *Aegis-RP* lockable bait stations were installed to replace the ageing drench containers. An eradication attempt occurred at about this time using one of the second-generation rodenticides but was likely unsuccessful due to stations not being regularly refilled beyond the initial bait-take because of difficulties accessing the island and stations not being deployed on the nearby western islet which connected to the main island at low tide.

Development of a rodent eradication plan for Big Green Island by PWS and Biosecurity Tasmania, both divisions within the Department of Primary Industries, Parks, Water and Environment (DPIPWE) commenced in 2013. In 2014 it was decided that all poison bait in the bait stations on the island needed to be removed as soon as practicable to reduce the possibility of rodents becoming physiologically tolerant to toxins due to consumption of sub-lethal doses of degrading bait. Flocoumafen and bromadiolone poison blocks were used until stations were removed in January 2015.

METHODS

The eradication project was managed by the PWS Flinders Island Field Centre with technical advice provided by Biosecurity Tasmania. A feasibility study was completed in January 2015 (Robinson & Dick 2015) and recommended ground baiting with stations. An operational plan (Robinson & Dick 2016) was finalised in February 2016 after being independently reviewed. In January 2015, 864 lockable plastic bait stations were collected, cleared of bait and cleaned. A low number of stations (c. 10) in thick vegetation were not located during this collection. In March 2016, an additional 1,193 new plastic rodent bait stations (*Aegis*) were taken by barge to the island.

The GPS-linked field data management program *Fulcrum* (www.fulcrumapp.com) was selected to manage the installation of stations on a 25 x 25 m grid (i.e.,16 stations/

ha) and bait delivery to this array. Data were recorded in real time and available to the baiting team once uploaded through the mobile phone network. Over 2,200 bait stations were installed by staff and volunteers between 8 and 13 March 2016 using mobile phone network-linked hand-held devices (iPads, Apple) preloaded with *Fulcrum* and a purpose-built eradication application ('app') with grid points on a *Google Earth* base-map. The accuracy of iPad GPS is described as 3–6 m, but it was usually within 1–2 m. Additional stations were installed around the buildings, increasing the density to a 12.5 m grid over 6.25 ha as a contingency for mice. It was decided the buildings would be the most likely place for mice, if still present on the island. A second *Fulcrum* 'app' was developed in June 2016 for tracking the location and use of monitoring devices across the island.

Islets and outcrops joined to the main island at low tide also had bait stations installed. Additional stations were placed around the coast giving a total of 2,208 bait stations by the end of May 2016. Stations were anchored using a 12 cm metal spike or a suitable rock. About 100 g of commercial rodent food pellets (Peckish™) were added to each station and left for five weeks to assist the habituation of rats to entering stations. Twenty rats were trapped for DNA as recommended by Broome *et al.* (2011) in March 2016. Bird and invertebrate surveys were conducted during April–May 2016 but are not reported on here. Sheep remained on the island for the duration of the program.

Baiting strategy

The baiting strategy was to use a grid of bait stations across the island with brodifacoum as the active ingredient in wax bait blocks as developed through discussions with the Tasmanian PWS staff, eradication experts in New Zealand, and from the 'Agreed Best Practice for using Bait Stations' (Broome *et al.* 2011). Stations were to have bait available for four weeks and checked daily, followed by another eight weeks of less frequent checking. It was recommended that baiting could cease one month after the last known bait-take and, if all went well, this would occur within the 12-week baiting period. Because the situation with House Mouse was unresolved, bait station spacing was reduced from the recommended 50 m (Broome *et al.* 2011) to a grid of 25 x 25 m. Though this was not a proven spacing for eradicating mice, it would likely provide a greater chance of success with mice if they were present, than 50 m. The alternatives were not considered feasible (i.e., 10 m grid spacing or aerial baiting). In addition, a 6.25 ha area around the buildings, the most likely place for mice if they were not island-wide, had the bait station grid reduced further to 12.5 m.

Stations were to be installed several weeks in advance of baiting to minimise neophobia in rats around the new bait stations and for baiting to begin in autumn. The breeding season of rats on Big Green Island was unknown but it was considered less likely they would be breeding in autumn and winter. Even if breeding was occurring, the strategy of maintaining baits in stations for 12 weeks should ensure any emerging juvenile rats would be exposed to bait.

Baiting

Talon X-Pro (Selleys) 20 g wax blocks containing 50 ppm brodifacoum were secured in stations from 26 April, with the addition of *X-Verminator* (Daviesway) c. 18g blocks (50 ppm brodifacoum) from 18 May onwards. Stations had bait checked and replenished daily from 26 April–22 May 2016 (28 days) followed by checks from 6–11 June, 20–26 June, and 4–10 July. Up to six teams of two people checked and replenished all bait stations every 1.5–2 days. A minimum of two baits were provided per station, but some had up to six baits at a time being consumed and these were replaced as needed. Baiting required volunteer teams of at least ten people for three consecutive ten-day shifts (equating to 28 days) followed by three further one-week shifts with at least six volunteers as described above. A total of 56 volunteers and six staff were engaged over the baiting phase of the project. A commercial supplier provided 200 kg of *Talon X-Pro* and agreed to hold an additional 200 kg in stock but this was not available when required. *X-Verminator* was used in its place. A Minor Use permit from the Australian Pesticides and Veterinary Medicines Authority was required for brodifacoum baits to be used for an 'off-label' application (i.e., away from buildings) and covered the use of both *Talon X-Pro* and *X-Verminator.*

During station checks, data on bait added to stations were entered into the *Fulcrum* 'app' so that bait consumption could be calculated. Minimal or zero consumption of the second bait *X-Verminator* occurred due to the rat population being near zero when this bait was deployed. There was also difficulty in distinguishing between possible consumption by rats and crumbling of this bait in some instances, thus no bait uptake estimates for *X-Verminator* are provided in the results.

Monitoring for rat activity

A range of rodent activity monitoring devices were deployed at various times from week six of baiting, and included chew cards (35 x 80 mm plastic corflute cards containing 5 grams of peanut butter), WaxTags (a waxy peanut butter lure which retains tooth marks; Pest Control Research Ltd. New Zealand) and Reconyx Hyperfire2 motion sensing cameras distributed in areas of boxthorn and tussock grass, the preferred habitat of rats. Snap traps (*Aegis*) were set 10–20 m apart in the areas where monitoring devices indicated rat activity. Other devices used for both monitoring and killing were A24 CO_2 powered traps (*GoodNature*) and 'rat motels' (700 x 700 x 150 mm, lidded marine ply box internally partitioned containing food, bedding, poison bait, wax tag, snap trap and two 70 mm entry holes) and baited stations. From late July to early December 2016, eight visits to the island of one week with two staff were undertaken. In 2017, three-day monitoring visits were undertaken every two months then reduced to every three months in 2018. A rodent detector dog trained for rats and mice visited the island on five occasions, beginning four months after baiting finished (i.e., November 2016). Two years of regular island-wide monitoring concluded the program in November 2018.

RESULTS

Stations and bait consumption

A total of 2,208 stations (tables 1 and 2) had 29,182 visits recorded between 26 April (Day 1) and 10 July 2016, with over 99% of the bait consumption occurring before 10 May 2016 (Day 15), the period when only *Talon X-Pro* was used (table 3 & fig. 2). Bait take was highest at Day 5 and decreased to zero (or wasn't discernible) at Day 20 (fig. 2). It was possible a small pulse of bait-take occurred around Day 43 but was difficult to measure due to being very small amounts. Fresh bait remained in stations until at least mid-July (Day 84). A low level of bait uptake recording errors occurred during data entry (typing errors, double entries). Obvious errors were corrected in the database and the remaining error (related to recording bait consumption) was estimated to be 4.4%. An estimated 200.6 kg ± 8.7 kg (4.4 %) of *Talon X-Pro* was consumed by rats (table 3). The highest bait consumption occurred in coastal areas of African Boxthorn and Tussock Grass, with the mid-east coast of the main island showing pockets of very high consumption (> 640 g, or 32 blocks, per 25 x 25 m grid square) (fig. 3). The first dead rat was seen on 28 April and a strong odour of dead rats was discernible by 10 May particularly on the west and north islets.

Locating remaining rats

Bait-take declined over time and appeared to be at zero by 21 May. Field staff noted, however, that in early June, small amounts of bait may have been consumed and in order to check for possible remaining rats, 381 chew-cards were deployed. These were placed 20–50 m apart and located where bait may have been consumed and in areas of preferred rat habitat including the vegetated perimeter of the island and features such as rocky outcrops between 3 and 8 June. On 10 June, damage to 21 chew-cards indicated rats were still present. In response, the project adopted intensive monitoring with chew-cards, wax tags, snap traps, cage traps, Elliott traps, motion-sensing cameras, tracking tunnels and CO_2 powered A24 traps (table 4). Chew-cards, and to a lesser extent wax tags, were the most effective tools for locating rat activity. Multiple snap traps with a variety of food lures were set in the areas where activity was identified. A total of six rats (3 male, 3 female) were killed in snap traps: three in June, two in July and one in November (fig. 4). The last known positive rat sign was an adult female rat killed on 3 November 2016. None of the three female rats were pregnant or lactating. No sign of mice was found.

The grid of baited stations remained in place until mid-July 2016 then was progressively removed over a three-week period beginning with the areas of pasture where bait consumption (a proxy for rat density) had been lowest. Over 30 baited stations were maintained at beaches, landing points and around buildings, in addition to those deployed where rat sign was located. Monitoring equipment remained in place from June 2016 to November 2018 (table 4),

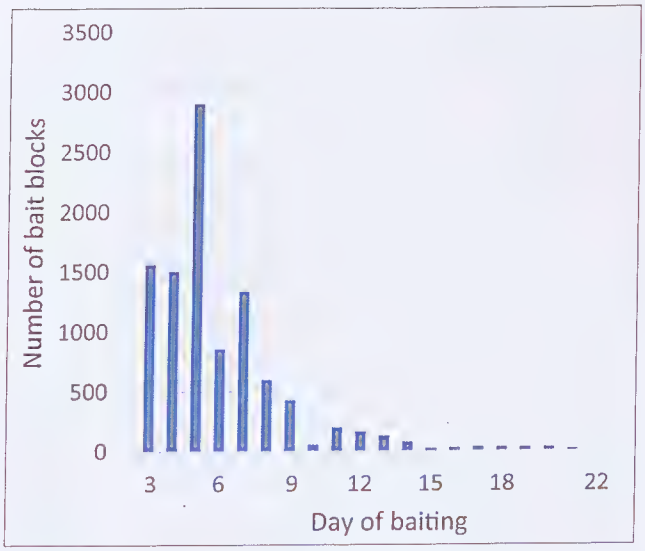

FIG. 2 — Number of 20 g bait blocks recorded consumed on each day from 28 April 2016 (Day 3) onwards. Initial baiting of stations occurred on Days 1 and 2. Two days were required to check all stations.

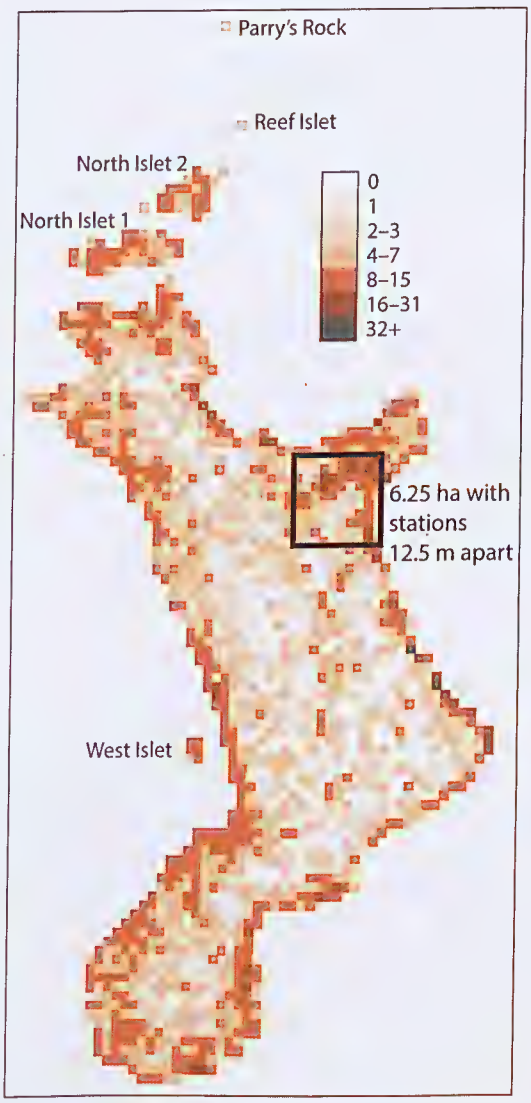

FIG. 3 — Bait block (*Talon X-Pro*) consumption per 25 x 25m grid square for all the areas of Big Green Island. The highlighted 6.25 ha square contained stations at higher density around the buildings.

TABLE 1 — Names and areas (above high tide) of individual islands, numbers of bait stations installed and *Talon X-Pro* bait consumed.

Site	Area ha	Number of stations	Bait consumed kg
Main island	124.80	2128	187.8
West Islet[1]	0.18	6	1.1
North Islet 1	2.26	40	6.9
North Islet 2	1.50	28	4.6
reef islet (no name)	0.06	2	0.1
Parry's Rock	0.11	2	0.1
TOTAL	128.91	2208	200.6

[1] Refer to Fig. 3 for locations of islets.

TABLE 2 — Station deployment and visit details.

	Total	Comment
Total 25 x 25 m grid squares	2064	Main island and islets combined
Additional stations over 6.25 ha	93	Contingency for House Mouse
Total stations	2208	Includes extra coastal stations
Visits to stations (26 Apr–17 May 16)	18,722	*Talon X-Pro* bait only
Visits to stations (18 May–10 July 16)	10,460	*X-Verminator* and *Talon X-Pro*

TABLE 3 — Bait deployment and consumption.

Measure	Total	Comment
Total 20 g blocks consumed	10,028	*Talon X-Pro* only
Total bait consumed (± error)	200.6 (± 8.7) kg	*Talon X-Pro* only
Average consumption /station	0.1 kg (5 blocks)	Averaged over 129 ha
Average consumption/ha	1.6 kg	Averaged over 129 ha
Total bait deployed	400 kg	Spoiled baits were removed

TABLE 4 — Monitoring tools deployed from 3 June 2016 to the end of the project on 3 November 2018.

Monitoring tool	3 Jun–27 Nov 16 [1]	02 Dec 16	28 May 17	12 Oct 17	19 Apr 18	22 Aug 18	1 Nov 18
Chew-cards	667	383	396	169	187	187	187
Snap traps	473	3	4	4	3	3	3
Cage traps	6						
Elliott traps	5						
CO2 trap locations	9	5	5				
Tracking tunnels	15						
Bait stations	c. 40	1	38	37	39	39	39
Wax tags	89	18					
Camera locations	16						
Rat motels			6	6	6	6	6
Rodent detector dog days	3		3	3	3		2.5

[1] Total installed over this period

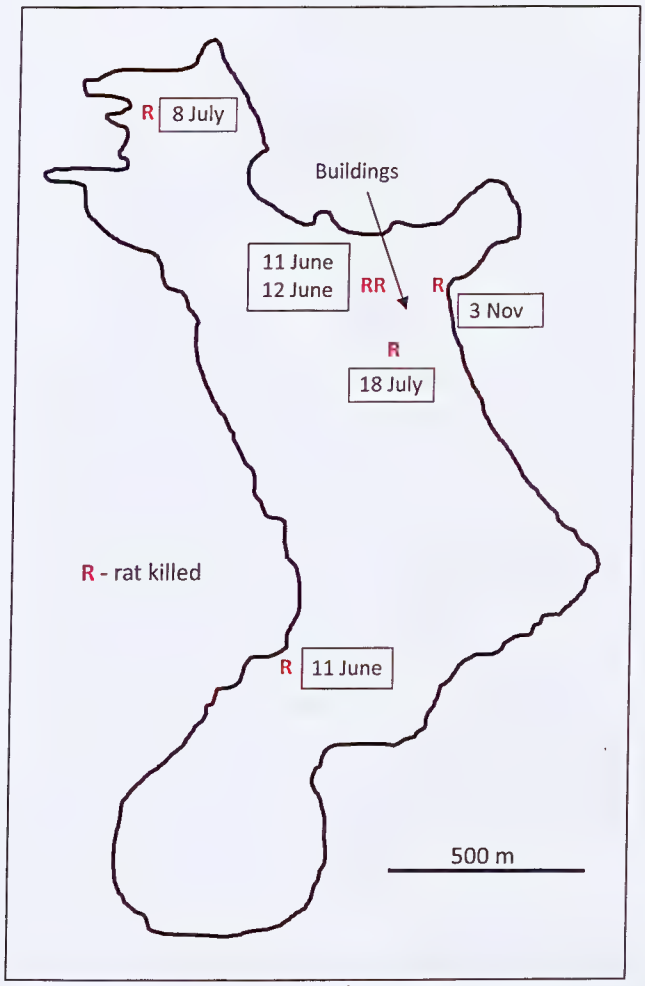

FIG. 4 — Dates and locations of rats killed by snap traps on the main island of the Big Green Island group subsequent to the main baiting knockdown.

which included a two-year monitoring period (Broome *et al.* 2011) with no further rat sign detected.

Non-target impacts

Baiting teams were highly vigilant for sick and dead rats with a total of 20 animals collected to reduce the possibility of secondary poisoning of non-target species. Five Pacific Gulls died from consuming poisoned rats as indicated by haemorrhaging seen externally on their carcasses. Trapping resulted in the deaths of three Brown Quail (*Coturnix ypsilophora*) in uncovered snap traps and a Cape Barren Goose hatchling that squeezed into a station containing a snap trap.

Effort and cost

Approximately 605 days of volunteer time supported the rat eradication work, with station deployment and baiting consuming the most time. Government agency staff contributed at least 408 days to the project.

Purchases of project equipment and services totalled $114,000. Total salary costs were estimated at $120,000. In Australia, volunteer time is costed at $41.72 per hour (Australian Bureau of Statistics 2018) making the volunteer contribution $201,925.

Biosecurity

A Biosecurity Plan (Tasmania Parks & Wildlife Service 2016) has been drafted for the island. To minimise biosecurity issues during the eradication program and the monitoring phase, public visitation to the island was suspended until at least November 2016. To reduce the risk of reinvasion of the island by rodents, supplies and equipment travelling to the island are now checked as part of ongoing biosecurity requirements overseen by PWS staff. For on-island biosecurity, six 'rat motels' and 32 baited stations are maintained on the island (including adjacent islets) with checks aimed at 3–6-month intervals.

DISCUSSION

Tasmania is notable for having achieved the world's largest Black Rat eradication: 12,800 ha Macquarie Island in 2011 (Springer 2016). Interestingly, apart from this and the Big Green Island attempt, the only other island rodent eradications in Tasmania were for the tiny 1 ha Fisher Island in 1974 for Black Rat (Serventy 1977) and again in 2013 for House Mouse and Black Rat (S. Robinson, unpublished data). Big Green Island was one of the 22 'uninhabited' Tasmanian islands recorded with invasive rats and had a long history of rodent control and a previous attempt at eradication. For the eradication attempt described here, potential non-target issues from primary poisoning (i.e., native species and livestock) were minimised by choosing bait stations as the eradication method. The 50 m grid recommended by Broome *et al.* (2011) was increased in density to a 25 m grid as a contingency for the possible presence of mice, accepting that the recommended grid for baiting mice is 10 x 10 m (Harper *et al.* in press). The 25 m bait station grid required a substantial labour force (mostly volunteers) to check stations over the 12-week baiting period and a data management system capable of tracking the distribution of bait over such an array.

The field data management program *Fulcrum* was integral to the project. Most volunteers quickly mastered the use of iPads and *Fulcrum* for recording data, though more training would have improved data quality and reduced errors. There were a number of small issues with the data input design related to inexperience of structuring an 'app' for this type of work. The baiting 'app' was not suitable for recording the dynamic situation with monitoring tools being deployed across the island, and a second 'app' specifically for monitoring needed to be produced. In hindsight the monitoring 'app' should have been available at the beginning of fieldwork alongside the baiting 'app'.

Rodent eradication projects on islands generally do not undertake intensive verification monitoring until two rat breeding seasons (equating to two years) after the knockdown (Broome *et al.* 2011), as for example, Macquarie Island (Springer 2016). This allows time for any rodents to increase in number to a detectable level. The potential issue with this method is that if rodents have survived the eradication attempt, allowing two

years of reproduction will likely mean the full eradication will need repeating and this additional cost may not be economically viable. The island-wide deployment of monitoring devices after the main knockdown period was not part of the original plan but was suggested by a rodent eradication expert (Department of Conservation, New Zealand) as a good way to check on how the operation was progressing. Other practitioners have used a similar idea and developed detailed rapid eradication assessment models (Samaniego-Herrera *et al.* 2013, Russell *et al.* 2017) where monitoring begins soon after baiting and these are particularly suited to smaller islands. A batch of 500 chew-cards was made on the island and these were available for deployment when field staff thought there could be some late bait consumption.

Chew-cards were checked in early June and indicated rat activity. It was possible these remaining rats could have been tolerant to brodifacoum due to the population's long history of exposure to rodenticides or were choosing not to consume bait or to enter bait stations and had thus avoided being poisoned at least at that stage. Bait was still available across the grid and in addition to this, in the case that rats were not entering stations or taking bait, managers decided to allocate staff to actively locate and capture rats, not knowing at the time if there was a high or a low rat population remaining. The appearance of a pulse of activity a few weeks after bait-take has declined to (near) zero is not unusual during a baiting operation (K. Springer pers. comm.). It may have been that remaining rats would have eventually consumed bait if they hadn't been trapped, but the team chose to act to ensure that other lethal methods were available in case the remaining rats were not susceptible to poisoning. Snap traps were firstly set inside stations, which was not successful, then outside of stations under debris and vegetation (to minimise potential bycatch). The main bait station grid was removed between late July and early August 2016 because it was thought remaining rats were avoiding stations, as seen in the lack of success with snap traps set inside stations. Six rats were caught in snap traps between June and November 2016, and no further sign was found during the next two years. The island was declared rat-free in November 2018.

Notwithstanding it is possible all rats could have eventually been killed with poison and that the monitoring could have been delayed, possible explanations for rats being present after the main period of bait consumption include:

Black Rat live for about one year in the wild (Strahan 1983). Ideally an island would be bait-free for at least one year prior to an eradication so that rats exposed to bait during their lifetime (and survived) have died from other causes. The bait-free period prior to eradication for Big Green Island was planned to start in January 2015 when all field-based stations were collected. It transpired in July 2015, however, that sheds and buildings were still being baited which reduced the island's bait-free period to eight months. It was therefore possible that rats that had been exposed to bait, and developed a tolerance to it during this period, could still have been alive at the time of eradication and avoided being poisoned.

The rat population's long history of exposure to multiple poisons may have resulted in the survivorship of neophobic or bait-tolerant individuals over time.

'Bitrex', a bittering agent, was present in the bait *Talon X-Pro* and rats may have been detecting it or repelled by it. Note, however, that *X-Verminator* was also present in stations and does not contain 'Bitrex' so rats may eventually have taken baits if they hadn't been trapped first.

Interestingly, four of the six remaining rats were trapped within 100 m of the buildings. The risks and implications related to long-term rodenticide use at islands selected for eradication need to be carefully considered during the planning phase. At sites where rodenticides have been used for many years, allowing two years for the site to be free of rodenticide would reduce the chance of bait-tolerant or neophobic individuals being present. This additional time may need to be included in future project planning.

Rat density and bait consumption

Using bait consumption as an index of rat density showed that native Tussock Grass and African Boxthorn were the most favoured habitats for rats. The highest rat density occurred on the mid-east coast in a narrow strip of African Boxthorn. The nearby islets (West, North Islets 1 and 2) also had high bait consumption (8–15 blocks/grid square) inferring high rat density. The small (30 x 20 m and 45 x 15 m), sparsely vegetated, rocky islets to the north also had rats present. These two outcrops join up at low tides. At the lowest tides, a shallow channel 100 m wide, exists between North Islet 2 and the unnamed 'reef islet', but is well within a rats' swimming ability, with studies concluding Black Rats can swim up to 1 km distance in favourable conditions (Spennemann & Rapp 1989), though 500 m is considered more realistic.

Project partnerships

The Big Green Island rat eradication project was supported by groups of up to 12 volunteers at a time. Volunteers assisted with a variety of tasks throughout the eradication process: deploying stations across the island; data collection; checking and rebaiting stations; removing stations; constructing, deploying and checking hundreds of chew-cards. Significantly, the grid of 2,208 bait stations would not have been an economical option for the project's budget if salaried staff were used. Pre-eradication surveys for birds and invertebrates were conducted by volunteers experienced in these fields.

More and more conservation work is being supported through alternative funding sources and thus projects like these must include strong partnerships between government, industry and non-government organisations. Both the volunteer and philanthropic contributions to this rat eradication project were critical to its success.

Maintaining a rodent-free island

Whilst having an island inhabited and with a livestock grazing lease presents challenges for maintaining biosecurity, the presence of the island's leaseholder likely reduces the numbers of opportunistic visitors and campers. Biosecurity guidelines for island visitors are provided on the PWS website. The local PWS staff have biosecurity processes in place to check stock-feed going to Big Green Island and have the responsibility of maintaining the island's rodent bait stations. The time and cost required for biosecurity-related tasks are significantly less than that expended for annual, island-wide and ongoing rodent baiting for control purposes. It is important to note that now the island is free of Black Rats, it is vulnerable to invasion by other species of rodents such as Brown Rats and House Mouse (but also reinvasion by Black Rats) all of which occur on Flinders Island, 3 km distance at the narrowest crossing. Brown Rats can swim 1 km (Russell *et al.* 2008) but have also been recorded swimming at least 2.5 km (K. Broome pers. comm.).

Post-eradication wildlife monitoring

Post-eradication monitoring includes the long-term Short-tailed Shearwater monitoring by the Tasmanian Government's Marine Conservation Program. Baseline information on invertebrates, shore birds and other birdlife were collected during the eradication project, and similar surveys will be repeated in the future to examine changes and recovery in native species.

CONCLUSIONS

Big Green Island has a long history of poison baiting which brought additional considerations into planning for a rat eradication. The project required detailed planning to operate over 2,200 bait stations, a task that was made possible by a mobile phone-linked data collection program and a large group of volunteers. The decision to monitor for rodent activity soon after the main bait consumption period was an important factor in the success of the project because it allowed surviving rats to be located and dispatched before breeding occurred. Effective and ongoing biosecurity for the island is critical for protecting the investment of this rat eradication program, with the island potentially vulnerable to colonisation from any of the three introduced rodent species that occur on nearby Flinders Island. Surveys of shorebirds and small burrowing petrels, as well as invertebrate and reptile fauna, will hopefully soon show the benefits of the work and commitment undertaken to remove Black Rats from Big Green Island.

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REFERENCES

Australian Bureau of Statistics 2018: *Assigning value to your volunteer labour,* https://www.fundingcentre.com.au/help/valuing-volunteer-labour

Backhouse, J. 1843: *A narrative of a visit to the Australian colonies.* Hamilton, Adams and Co., London: 560 pp.

Banks, P.B. & Hughes, N.K. 2012: A review of the evidence for potential impacts of black rats (*Rattus rattus*) on wildlife and humans in Australia. *Wildlife Research* **39:** 78–88.

Broome, K.G., Brown, D., Cox, A., Cromarty, P., McClelland, P., Golding, C., Griffiths, R. & Bell, P. 2011: *Current Agreed Best Practice for Rat Eradication – poison bait in bait stations (Version 1.3).* New Zealand Department of Conservation internal document DOCDM-839096. Department of Conservation, Wellington, New Zealand: 25 pp.

Brothers, N.B., Pemberton, D., Pryor, H. & Haley, V. 2001: *Tasmania's Offshore Islands: Seabirds and Other Natural Features.* Tasmanian Museum and Art Gallery, Hobart, Tasmania: 643 pp.

Commonwealth of Australia 2009: Threat Abatement Plan to reduce the impacts of exotic rodents on biodiversity on Australian offshore islands of less than 100 000 ha. Unpublished Report of the Department of the Environment, Water, Heritage and the Arts, Canberra: 24 pp.

Global Invasive Species Database 2019: *100 of the World's Worst Invasive Alien Species,* www.iucngisd.org/gisd/100_worst.php (accessed 18 August 2019).

Harper, G.A., Pahor, S. & Birch, D. (*in press*) The Lord Howe Island rodent eradication: lessons from the ground-baiting operation. 29th Vertebrate Pest Management Conference. University of California (Davis), USA.

Harris, S., Buchannan, A. & Connolly, A. 2001: *One Hundred Islands: The Flora of the Outer Furneaux.* Tasmanian Department of Primary Industries, Water and Environment, Hobart: 361 pp.

Norman, F.I. 1970: Food preferences of an insular population of *Rattus rattus. Journal of Zoology, London* **162:** 493–503.

Robinson, S. & Dick, W. 2015: Big Green Island Black Rat Eradication Feasibility Report. Unpublished Report for Tasmanian Parks and Wildlife Service. Hobart: 22 pp.

Robinson, S. & Dick, W. 2016: Big Green Island Black Rat Eradication Operational Plan. Unpublished Report for Tasmanian Parks and Wildlife Service. Hobart: 23 pp.

Russell, J.C., Binnie, H.R., Oh, J., Anderson, D.P. & Samaniego-Herrera, A. 2017: Optimizing confirmation of invasive species eradication with rapid eradication assessment. *Journal of Applied Ecology* **54:** 160–169.

Russell, J.C., Towns, D.R. & Clout, M.N. 2008: Review of Rat Invasion Biology. Implications for island biosecurity. Science for Conservation No. 286. Unpublished Report of the Department of Conservation, Wellington, New Zealand: 54 pp.

Samaniego-Herrera, A., Anderson, D.P., Parkes, J.P. & Aguirre-Munoz, A. 2013: Rapid assessment of rat eradication after aerial baiting. *Journal of Applied Ecology* **50:** 1415–1421.

Serventy, D.L. 1977: Seabird Islands: Fisher Island, Tasmania. *Corella* **1(3)**: 60–62.

Spennemann, D.H.R., Rapp, G. & Early, D.S. 1989: Can rats colonise oceanic islands unaided? An assessment and review of the swimming capabilities of the genus Rattus (Rodentia: Muridae) with particular reference to tropical waters. *Zoologische Abhandlungen des Museums für Tierkunde Dresden*, **45(1)**: 481-491.

Springer, K. 2016: Methodology and challenges of a complex multi-species eradication in the sub-Antarctic and immediate effects of invasive species removal. *New Zealand Journal of Ecology* **40**(2): 273–278.

Strahan, R. (ed) 1983: *Complete Book of Australian Mammals.* The Australian Museum, Sydney: 530 pp.

Tasmania Parks & Wildlife Service 2016: Big Green Island Biosecurity Management Plan 2016. Draft Report for Parks and Wildlife Service, Hobart: 21 pp.

Towns, D.R., Atkinson, I.A.E. & Daugherty, C.H. 2006: Have the harmful effects of introduced rats on islands been exaggerated? *Biological Invasions* **8**: 863–891.

Van Dyck, S.M. & Strahan, R. (eds.) 2008: *The Mammals of Australia.* New Holland Publishers, Sydney: 887 pp.

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UNVIABLE FERAL CAT POPULATION RESULTS IN ERADICATION SUCCESS ON WEDGE ISLAND, TASMANIA

by Susan Robinson and Luke Gadd

(with one text-figure and one table)

Robinson, S. & Gadd, L. 2020 (9:xii): Unviable feral cat population results in eradication success on Wedge Island, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 154: 47–50. ISSN: 0080–4703. Biosecurity Tasmania, 13 St Johns Avenue, New Town, Tasmania 7008, Australia (SR*); Tasmania Parks and Wildlife Service, Mt Field National Park, 66 Lake Dobson Road, National Park, Tasmania 7140, Australia (LG). *Author for correspondence. Email: sue.robinson@dpipwe.tas.gov.au

Wedge Island in southeast Tasmania is 43 ha in size and is habitat for Little Penguin (*Eudyptula minor*) and Short-tailed Shearwater (*Ardenna tenuirostris*) populations. The island was subject to a feral Cat (*Felis catus*) eradication attempt in 2003 when 13 cats were captured with the assistance of trained detection dogs. It was known at least one cat remained. No further cats were captured during two subsequent visits in 2003 and 2004 and a single dead cat was found in 2012. It appeared the cat population never recovered from the initial knockdown and this ultimately resulted in eradication success. Methods used and details of cats caught are provided and the program is discussed in terms of criteria required for a successful eradication.

Key Words: island eradication, feral Cat, *Felis catus*, eradication criteria, Tasmania.

INTRODUCTION

Like other islands of the world, Tasmania's offshore islands have been subjected to deliberate and inadvertent introductions of non-native vertebrates, typically rats (*Rattus rattus* or *R. norvegicus*), House Mouse (*Mus musculus*), European Rabbit (*Oryctolagus cuniculus*) and Cat (*Felis catus*). Cats have been taken to islands by residents as companion animals and to control pest rodents that have established after arriving in cargo; rabbits have historically been introduced to islands as a food source for fishers, residents and mariners.

Around 10% of Tasmania's 600 vegetated islands and islets are recorded as having vertebrate pests and at least 20 islands have had cats introduced. Feral cats were eradicated from two islands in the Furneaux Group (Little Green and Great Dog) in the 1980s (Campbell *et al.* 2011), from subantarctic Macquarie Island in 2000 (Robinson & Copson 2014) and from Tasman Island in 2010 (Robinson *et al.* 2015). After the Macquarie Island cat eradication monitoring period concluded in 2002, staff, traps and cat detection dogs became available for use on further projects. The removal of feral cats from Wedge Island, southeast Tasmania, was attempted in 2003 with support from the Marine Conservation Program, Department of Primary Industries, Parks, Water and Environment (Tasmania).

European Rabbit and Sheep (*Ovis aries*) were introduced to Wedge Island in 1930 by fishers (N. Brothers quoted in Beh 1995). Rabbits outcompeted the sheep for food, so the sheep were removed in 1939. Cats were first recorded on the island in 1939 and were probably introduced for rabbit control. It appears these cats died out some years later (Beh 1995). Sheep were then returned to the island at a subsequent unknown date prior to 1970. *Myxoma* virus was released on Wedge Island through the 1970s, and in 1976 cats were re-introduced (apparently one pregnant female) to help control the rabbits that were again impacting vegetation and sheep grazing (Beh 1995). The rabbits died out around 1978 and the sheep were removed in 1986 but cats remained (Beh 1995). No rodents or other introduced mammals are present on the island, leaving seabirds as the main food source for cats.

STUDY SITE

Wedge Island (43°08'S, 147°40'E), located on the western side of the Tasman Peninsula, was reserved as a Conservation Area in 2004 and is 800 m in distance from the closest point to mainland Tasmania. Orientated north–south, Wedge Island is approximately 1.3 by 0.6 km with an area of 43 ha. The island has steep dolerite cliffs on the western side tapering to a rocky shoreline in the east. The island rises to 96 m. Tussock Grass (*Poa poiformis*) and Saggs (*Lomandra longifolia*) are the dominant vegetation with patches of succulents (*Carpobrotus rossii*), Kangaroo Apple (*Solanum laciniatum*) and a small remnant eucalypt (*Eucalyptus viminalis*) and she-oak (*Casurina* sp.) woodland (Brothers *et al.* 2001).

The island has a significant seabird fauna, including 12,000 pairs of Short-tailed Shearwaters (*Ardenna tenuirostris*) and 1000 pairs of Little Penguin (*Eudyptula minor*) (Brothers *et al.* 2001, Vertigan 2010). Other vertebrates include the Tasmanian Native Hen (*Gallinula mortierri*) and two species of skink (*Niveoscincus metallicus* and *N. ocellatus*). Fairy Prions (*Pachyptila turtur*) are believed to have been breeding on the island up to the 1970s (N. Brothers quoted in Beh 1995). Fur seals (*Arctocephalus pusillus* and *A. forsteri*) are present on the coastal rock platform.

METHODS

Field teams of two people camped on the island three times during 2003 and 2004. Methods available to capture cats

were wire mesh drop-door cage traps (600 x 300 x 300 mm) (Mascot Wireworks, Preston, Victoria), rubber-jawed leg-hold traps (Victor, no. 3: Woodstream Corp. Lititz, PA, USA) and shooting with a .22 calibre rifle under spotlight or when located by trained cat detection dogs.

Brief visits to the island to check for cat signs (footprints in sand or scats, etc.) were made opportunistically from 2007 to 2010. Four remote sensing cameras (*Scoutguard* SG-550) were installed on the island for four weeks during September and October 2008 and nine *Reconyx Hyperfire* remote sensing cameras from January to April 2012 and again from May to July 2012. Whilst land managers were generally confident no cats remained from 2012 onwards, the availability of a cat detection dog facilitated an additional final check for cat sign in 2019.

RESULTS

The effort to eradicate and monitor the cat population on Wedge Island is summarised in table 1. A primary knockdown of 14 days in 2003 was followed by 12 days of further effort but this was insufficient to capture the last cat/s. The project was unable to gain additional investment support for several years. In 2003, 13 cats were captured and at least one cat was known to remain giving a population of at least 14 individuals. At least one cat was known to be present until December 2010. This cat likely died in late 2011 and its body was found in May 2012.

Thirteen cats were captured in 2003: seven adult males (mean 4.1 ± SD 0.3 kg, n=7), five adult females (mean 2.9 ± SD 0.6 kg, n=4) and one juvenile female in poor condition (1.1 kg). Of these cats, 12 were white with patches of tabby, tortoise-shell or black, and a single animal had a solid tabby pelage. Three of the males had very worn teeth and one had a tattooed ear from the Beh (1995) study. The cat found dead in 2012 was a tabby.

For the first island visit (21 July to 4 Aug 2003) cage traps and leg-hold traps were set for cats. No cats were caught in either trap type. All cats captured over this 14-day period were located in seabird burrows as indicated by two detection dogs (fig. 1). Burrows were dug open by hand and cats humanely euthanised with a .22 calibre rifle. A second visit (27 Aug to 4 Sep 2003) was unsuccessful in capturing cats. Cat prints in sand and a freshly killed Little Penguin were recorded. During a four-day field trip in winter 2004, cat sign was again found (prints, scent and scats) but no capture resulted.

Stomach contents from cats euthanised in 2003 mostly contained remains of Little Penguins, including body parts of small chicks and adults. In July 2003, Little Penguins were incubating eggs or recently hatched young. Fish was present in cat diet and could have been from penguin stomachs or scavenged from the shoreline. Invertebrates were also present (beetles and caterpillars, species not identified).

With the total number of cats being at least 14 individuals in 2003, the density for Wedge Island was around 0.33 cats per ha. From the detailed field notes of Nigel Brothers in 1984 (State Library of Tasmania Archives), 15 to 17 individual cats could be identified for Wedge Island, 12 of which were trapped and tagged over 12 days in July and August 1984 as part of an unpublished energetics study. The ecological study by Beh in 1995 estimated "not more than a total of 15 individuals (cats) on the island".

TABLE 1 — Visits to Wedge Island: eradication effort and cat sign recorded from 2003 to 2019.

Trip date	Trip days	Staff days	Dog days	Trap nights		Spotlight hours	Camera nights	Cats	Comments
				Cage	Leg-hold				
21 Jul 03	14	14	28	273	210	30	–	13 dead	At least 1 cat (tabby) remaining
27 Aug 03	9	9	18	45	75	24	–	–	Cat scent detected by dogs; cat prints and scats
29 Jun 04	4	4	8	12	60	12	–	–	Cat scent detected by dogs; cat prints and scats
7 Sep 07	0.25	0.25	–	–	–	–	–	–	Cat prints
5 Sep 08	1	0.5	–	–	–	–	160	–	Cat prints and scats; no cats recorded on cameras
23 Aug 10	0.25	0.25	–	–	–	–	–	–	Cat prints
17 Dec 10	≈20	–	–	–	–	–	–	1 live	Tabby. Observation by University of Tasmania
23 Jan 12	1	3	1	–	–	–	–	–	2 old scats. No fresh scent located by dog
11 Apr 12	1	1	–	–	–	–	711	–	No cats recorded on cameras
31 May 12	1	7	1	–	–	–	–	1 dead	Tabby, desiccated; no fresh scent located by dog
13 Jul 12	1	1	–	–	–	–	344	–	No cats recorded on cameras
27 Sep 19	1	1	1	–	–	–	–	–	No sign of cats found

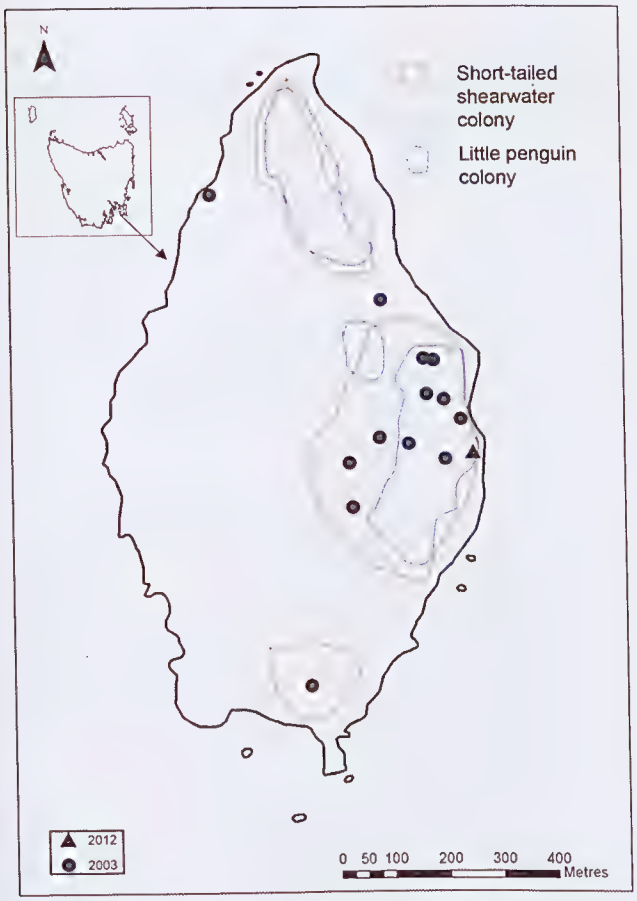

FIG. 1 — Map of Wedge Island, southeast Tasmania, showing locations of cats caught in 2003 (dots) and found dead in 2012 (triangle); seabird distribution is from Beh (1995) and Vertigan (2010).

DISCUSSION

In 2003, it was likely the Wedge Island cat population was reduced to either one cat or to a low number of cats of the same sex. This outcome left the cat population unviable and it died out in 2011. In 2012, with the establishment of the 'Invasive Species Branch' as part of Biosecurity Tasmania, it was decided to finalise the project through monitoring and locating any remaining cats. Camera monitoring and a thorough search of the island with a team of seven people and a cat detection dog found one dead cat that had likely died several months earlier. No other evidence or fresh cat sign has been found since.

The most effective method of locating cats on Wedge Island was with cat detection dogs indicating which seabird burrows were occupied by a cat. Interestingly, no cats entered cage or leg-hold traps. Dissected cats showed full stomachs of mostly Little Penguin remains, suggesting food was plentiful in July and why food lures in traps were not effective. Leg-hold traps were set outside the seabird colonies to avoid catching Little Penguins. It appeared that cats were mostly denning and feeding within the seabird colonies thus may have not encountered the leg-hold traps. It is possible the remaining cat/s retreated to the inaccessible southwest cliffs to avoid the high level of human and dog activity during field trips and thus evaded capture. In hindsight, poison baiting could have helped target remaining cats in the autumn when seabirds are absent and food availability low.

For island-based vertebrate pest eradication attempts to be successful, it is accepted that several criteria need to be met (Bomford & O'Brien 1995, Clout & Veitch 2002). These criteria are:

- Animals must be killed faster than they reproduce;
- All animals can be put at risk by the methods used;
- Immigration is zero;
- Methods are socially acceptable;
- The project has sufficient institutional support and funding.

The Wedge Island cat eradication attempt in 2003–04 was undertaken on a very small budget. After an effective primary knockdown, the follow-up effort and methods were insufficient, or not appropriate, to catch the last individuals (i.e., Criterion 2 was not met). No further funding was available to support the project (i.e., Criterion 5 was not met) after 2004. Cat activity on the island was sporadically monitored over the ensuing eight years, often in addition to boat trips already occurring in the area. Despite the criteria for eradication apparently not being met, the eradication was eventually successful because the remnant cat population was not reproductively viable, i.e., Criterion 1 had actually been met but this was not known at the time.

Another Tasmanian island where an eradication of cats was attempted on a limited budget was Tasman Island, 29 km to the southeast of Wedge Island. Seven visits between 1977 and 1982 utilised shooting and 1080 baits to remove cats. Population reduction was being achieved and further visits planned (Brothers 1982). The final effort to remove the cats, believed to be very low in number (e.g., three or less) did not occur (N. Brothers pers. comm.), and highlights the importance of securing sufficient resources for eradication work. The remnant cat population unfortunately recovered rather than dying out but was finally eradicated in 2010 (Robinson *et al.* 2015).

The cats on Wedge Island fed primarily on seabirds because most other common prey species were not present (e.g. rats, House Mice or European Rabbits). In 1984, Brothers (1984) noted 13 adult Little Penguins killed and/or consumed by cats over 12 field days during July and August. Examination of cat scats between May and September 1995 (Beh 1995) had Short-tailed Shearwater as the most prevalent dietary item in May (prior to their northward migration) and Little Penguin increasing with a peak in July. Native Hen remnants were also present in smaller proportions throughout Beh's 1995 study period. Eggshell fragments in scats increased in July and were likely from the eggs of Native Hens or Little Penguins. Beh (1995) reports caterpillars (species not recorded) increasing in prevalence in cat diet from July to September. Little Penguins and Native Hens, with the addition of caterpillars, supported cats through the low-food months when Short-tailed Shearwaters were absent. Some of the adult cats captured in 2003 showed extreme wearing

of teeth, suggesting items like intertidal limpets (Class Gastropoda) or mussels (Class Bivalvia) may have been prised from rocks and consumed.

The tabby coat colour of cats was not common on Wedge Island in 2003, with only two of 14 recorded with this pelage. It is feasible the tabby coloured cat observed in 2003, 2004 and 2010, and found dead in 2012, was in fact the same animal. This would give a minimum age of nine years at its death. From an ear-tattooed cat found in 2003, marked in the Beh (1995) study, it was known that cats on Wedge Island could live at least eight years. Interestingly, the cat coat colours recorded by Brothers in 1984 were mostly tabby (9 of 12 trapped) with others being tabby with a white front (2), white with black patches (1) or all black (1). Beh (1995) did not describe coat colours but provided a black and white image of a tabby or tortoiseshell cat with white legs and underparts.

CONCLUSION

Leaving individuals remaining on an island is not a recommended or desired outcome, but when island-based pest eradication work is undertaken on a very low budget, there can be higher risks to achieving success. Detecting survivors can be labour-intensive and costly, and projects may be left without sufficient funds. Fortunately for Wedge Island and its seabirds, the eradication of cats was eventually successful despite the presence of survivors. The primary knockdown left the remnant cat population, which could have been a single animal, so low that reproduction was impacted. This resulted in an unviable population that ultimately died out.

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REFERENCES

Beh, J.C.L. *1995: The winter ecology of the feral cat, Felis catus (Linnaeus 1758), at Wedge Island, Tasmania. Unpublished BSc Honours thesis, University of Tasmania, Hobart.*

Bomford, M. & O'Brien, P. *1995: Eradication or control for vertebrate pests? Wildlife Society Bulletin* **23**: *249–255.*

Brothers, N. 1982: Feral cat control on Tasman Island. *Australian Ranger Bulletin* **2:** 9.

Brothers, N. 1984: Original field notebook 24/8/84 Wedge Island. NS2366/1/67 State Library of Tasmania Archives, Hobart.

Brothers, N., Pemberton, D., Pryor, H. & Halley, V. 2001: *Tasmania's Offshore Islands: Seabirds and other Natural Features.* Tasmanian Museum and Art Gallery, Hobart, Tasmania: 643 pp.

Campbell, K. J., Harper, G., Algar, D., Hanson, C.C., Keitt, B. S. & Robinson, S. 2011: Review of feral cat eradications on islands. *In* Veitch, C.R., Clout, M.N. & Towns, D.R. (eds.): *Island Invasives: Eradication and Management.* Gland, Switzerland. Proceedings of the International Conference on Island Invasives, IUCN: 37–46.

Clout, M.N. & Veitch, C.R. 2002: Turning the tide on biological invasion: the potential for eradicating invasive species. *In* Clout, M.N. & Veitch, C.R. (eds.): *Turning the Tide: The Eradication of Invasive Species.* Gland, Switzerland and Cambridge, UK. Proceedings of the International Conference on Island Invasives, IUCN: 1–3.

Robinson, S.A. & Copson, G.F. 2014: Eradication of cats (*Felis catus*) from subantarctic Macquarie Island. *Ecological Management & Restoration* **15(1)**: 34–40.

Robinson, S., Gadd, L., Johnston, M. & Pauza, M. 2015: Long-term protection of important seabird breeding colonies on Tasman Island through eradication of cats. *Journal of Ecology New Zealand* **39(2)**: 316–322.

Vertigan, C. 2010: The life-history of short-tailed shearwaters (*Puffinus tenuirostris*) in response to spatio-temporal environmental variation. Unpublished PhD thesis, University of Tasmania, Hobart.

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COLLECTING HISTORY AND DISTRIBUTION OF THE POTENTIALLY INVASIVE *DISA BRACTEATA* (SOUTH AFRICAN ORCHID) IN TASMANIA

by Mark Wapstra, Matthew L. Baker and Grant D. Daniels

(with two text-figures, five plates and one table)

Wapstra, M., Baker, M.L. & Daniels, G.D. 2020 (9:xii): Collecting history and distribution of the potentially invasive *Disa bracteata* (South African orchid) in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 154: 51–60. ISSN: 0080–4703. Environmental Consulting Options Tasmania, Lenah Valley, Tasmania 7008, Australia (MW*); Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Sandy Bay, Tasmania 7005, Australia (MLB); North Barker Ecosystem Services, Hobart, Tasmania 7000, Australia (GDD). *Author for correspondence. Email: mark@ecotas.com.au

The collecting history of *Disa bracteata* Sw. (South African orchid) in Tasmania (Australia), the state's only naturalised member of the Orchidaceae family, is presented. Details of its distribution in Tasmania, since it was first discovered in 2005, are included and discussed with information on habitat, abundance and management. The species is primarily distributed across the north coast (Smithton to Musselroe) with an outlier in Huonville in the state's south. Most sites are from verges along public roads and highways, but the species has also been detected on several private properties and other less disturbed habitats. Many sites with the species have been actively managed with the objective of eradication, although some sites are now well-established so eradication will require concerted effort. It is recommended that the species be added to the Tasmanian *Weed Management Act 1999* as a declared species with the primary objective of eradication.
Key Words: *Disa bracteata*, Orchidaceae, distribution, naturalised, weed, invasive.

INTRODUCTION

The Orchidaceae family is extremely widespread and diverse, with an almost cosmopolitan distribution, and its species can be found growing in a wide range of habitats except for the most arid. It is one of the largest plant families, with estimates suggesting it contains up to 30,000 species (Mabberley 2008, Chen *et al.* 2009). Being such a large group of plants, it is surprising that its members are relatively uncommon as naturalised species (e.g. Ackerman 2007). For example, of the nearly 1,400 species that are recorded in China, only one is considered to be naturalised (Chen *et al.* 2009); and of New Zealand's ca. 117 species, only three are considered to be naturalised (Gardner & de Lange 1996, Howell & Sawyer 2006, Breitwieser *et al.* 2018). A similar pattern occurs in Australia, where a small number of species (*Arundina graminifolia* (D.Don) Hochr., *Disa bracteata*, *Epidendrum* sp., *Eulophia graminea* Lindl., *Serapias neglecta* De Not., *Vanilla planifolia* Jacks. ex Andrews) are reported to have become naturalised, compared to some 1,300 native species (Jones 2006, Clements & Jones 2008, Conran *et al.* 2011). In most cases, these are localised occurrences of species that have escaped cultivation (Jones 2006). The subject of this paper, *D. bracteata*, is widely naturalised in parts of southern Australia and is far more capable of self-establishment and long-distance dispersal than any other introduced orchid.

The genus *Disa* Bergius contains over 160 species and is naturally distributed in sub-Saharan Africa, the Arabian Peninsula, Madagascar and the Mascarene Islands (Leistner 2000, Goldblatt & Manning 2000, Mabberley 2008). The highest diversity for the genus occurs in southern Africa, with 131 species (Leistner 2000).

Disa bracteata (plate 1, plate 2) is endemic to South Africa where it is widespread and common throughout the highly diverse fynbos that extends across the Western Cape and Eastern Cape provinces (Linder 1981). In its natural range it grows in undisturbed and disturbed habitats but is most frequent and abundant in areas of disturbance such as neglected pasture, roadsides and wasteland where it is considered a pioneer species (Linder 1981). It has been recorded in a wide range of habitats, including those with light and heavy soils, from sea level to 1,500 m a.s.l., grows in full sun or shade and tolerates a wide range of rainfall regimes (Linder 1981). The species is a deciduous perennial geophyte that grows up to 40 cm tall. Each plant produces numerous leaves and a single, stout, cylindrical flowering spike. It dies back in summer and overwinters as a pair of fleshy tubers. The species flowers from late spring through summer. The self-pollinating flowers produce prodigious quantities of minute seed (Jones 2006) that are readily spread over long distances primarily via wind, but also through other vectors such as contaminated soil on vehicles. The tubers produce numerous fleshy roots that make uprooting entire plants by hand almost impossible in all but the sandiest of soils (M. Wapstra pers. obs.).

With its broad tolerance to a wide range of habitats, prolific seed production and its success as a pioneer species, it was perhaps not surprising that *D. bracteata* became widely naturalised in Australia (fig. 1), one of many plant species from South Africa to have successfully done so (e.g. Scott & Delfosse 1992, Scott & Panetta 1993). Jones (2006) noted that its introduction to Australia remains a mystery, with anecdotal statements suggesting that it arrived in Australia on ships from South Africa in the eighteenth century. Several species, and horticulturally derived hybrids of *Disa*, are cultivated for their ornamental appeal (Synge 1977). However, *D. bracteata* is purported to not be widely used in horticulture. It was first detected in Australia in 1944 from the rural district of Youngs Siding, near the port city of Albany, in Western Australia. At the time it was thought

PLATE 1 — *Disa bracteata* (**A**) in situ at Latrobe site and (**B**) excavated. (Image: P. Tonelli)

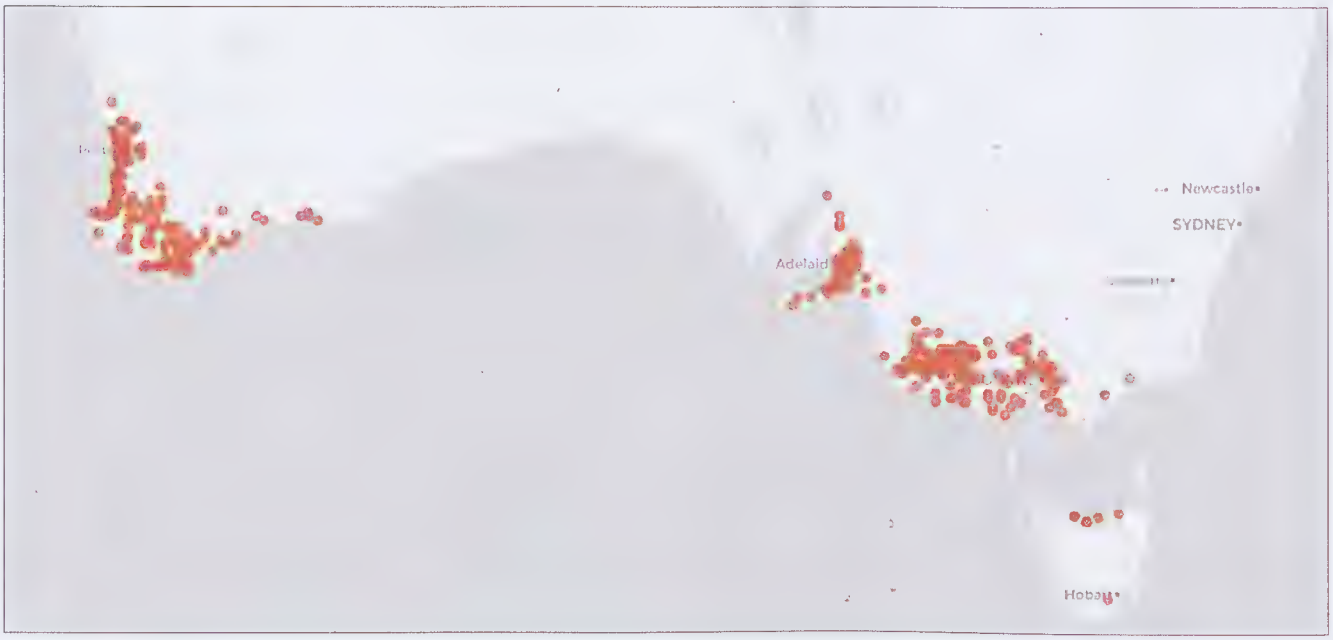

FIG. 1 — Distribution of *Disa bracteata* in Australia (source: Atlas of Living Australia, 8 August 2020).

PLATE 2 — (**A**) Clump of *Disa bracteata* in situ on Badgers Head Road, (**B**) close-up image of whole plant , and (**C**) hand-pulled plant showing lack of tubers and roots, which have remained embedded in the ground. (Images: M. Wapstra)

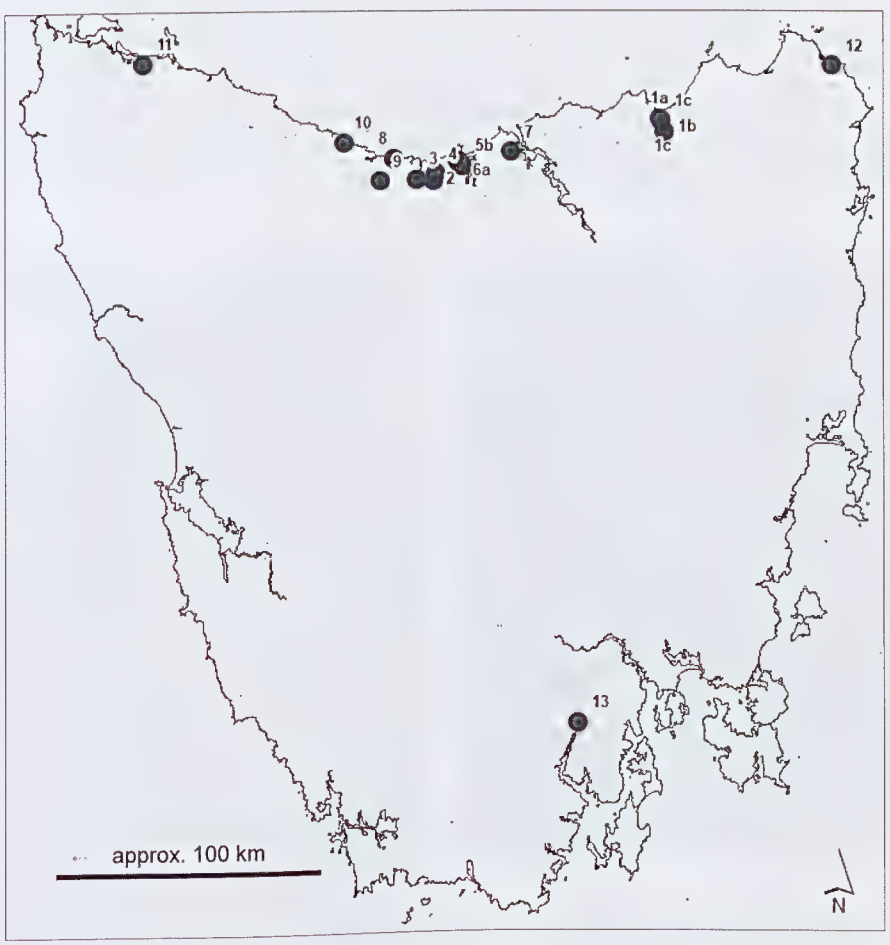

FIG. 2 — Distribution of *Disa bracteata* in Tasmania (numbers cross-reference to table 1).

to be a newly recorded native species and was described as *Monadenia australiense* Rupp (Rupp 1947). Since its discovery, it has become widely naturalised in southwestern Western Australia between Cervantes and Esperance. In South Australia, where it was first discovered in 1988, it is most common in and around the Adelaide Hills area, through to the Fleurieu Peninsula and Kangaroo Island, and around Mt Gambier. In Victoria, the species was first formally recorded in 1994 and is now widespread across southwestern Victoria and eastern parts of Gippsland. The only other region of Australia where it occurs is in Tasmania, where it was first detected in 2005 from a roadside near Bridport in the state's northeast. In Australia, *D. bracteata* is commonly referred to as the 'South African orchid' or 'African weed-orchid'.

In Western Australia, South Australia and Victoria *D. bracteata* is regarded as a significant environmental weed with a propensity to spread and invade bushland (Richardson *et al.* 2016), although there is little empirical evidence that shows it has a serious negative ecological impact. In Tasmania, the species is still in the early stages of establishment but with the recent discovery of new populations, the purpose of this paper is to document its current extent of occurrence, identify areas potentially at risk of invasion and describe how weed management legislation may aid in eradication efforts.

METHOD

Database and collection review

Several sources of records of native plants were interrogated and reviewed to produce a complete list of all known locations of *D. bracteata* in Tasmania. These were as follows: collections at the Tasmanian Herbarium, Tasmanian Museum & Art Gallery (HO); Department of Primary Industries, Parks, Water & Environment's *Natural Values Atlas* database (NVA, DPIPWE 2020); *Atlas of Living Australia* (ALA 2020); the Australasian Virtual Herbarium (AVH 2020); public Facebook groups *Tasmanian Native Orchids, Tasmanian Weeds, Tasmanian Flora* and *Field Naturalists of Tasmania* (with several 'posters' contacted direct for additional information); and iNaturalist (with the search terms 'Disa' and 'South African orchid') (www.inaturalist.org, accessed 19 August 2002).

The data were 'cleaned' to produce a definitive worksheet of known locations of the species. 'Cleaning' included removal of obvious database duplicates; removal of records lacking sufficient information to precisely place the site, and shifting of point locations to more precise sites where sufficient information was provided (e.g. records currently shown in the sea were shifted to a nearby terrestrial location if collection notes indicated an obvious location). Data were managed in Excel and transferred to ArcGIS for review.

Field survey

Field surveys were opportunistic by the authors as part of other ecological assessments or undertaken by the observers noted in Table 1 (and information gathered through personal communications). The intent of field surveys was to document abundance and extent, as well as persistence potential and threat to adjacent native vegetation (if present).

Where practical, observed plants were removed by trowel (to gather the tuber and root system), bagged and removed from the site. Some specimens were curated to create voucher collections for the Tasmanian Herbarium and several sites were visited on numerous occasions (noted in table 1).

PLATE 3 — Examples of excavated plants showing tubers. (**A**) Badger Head Road, October 2015; (**B**) Bass Highway, March 2016). (Images: M. Wapstra)

TABLE 1 — Collection details of all Tasmanian populations of *Disa bracteata*.

Site No. [1]	Location [2]	Details [3]	Comments
1a	"Bridport Road, 4 km SE of Bridport"	T: State Growth I: Flinders M: Dorset N: North	14 Nov. 2005, HO536631, A. Jungalwalla & D. Farmery. "Roadside verge" (from HO536631). This is the first formal collection of *D. bracteata* from Tasmania. Unfortunately, at the time of collection there was confusion as to whether the specimen had been collected from Bridport Road or Greens Beach Road, but the collectors have indicated that Bridport Road is the most likely. Further discussions indicated that they had "recalled several plants" although only one was submitted. "On 6 Dec. 2005, the site was surveyed by Alan Gray, Alex Buchanan and Matthew Baker from the Tasmanian Herbarium along with Jamie Cooper, the North East Regional Weed Officer. The species in question was not found" (from HO536631).
1b	Bridport Road	T: State Growth I: Flinders M: Dorset N: North	2 Mar. 2016, no specimen, A. North. Single, seasonally dead, roadside plant on Bridport Main Road between Bridport and Scottsdale near junction with Duncraggen Road; in a scattered infestation of spanish heath sprayed in January; "unfortunately looks like it has shed seed" (A. North pers. comm.). This is effectively the same site as the original population (1a).
1c	Bridport Road	T: State Growth I: Flinders M: Dorset N: North	17 Dec. 2017, no specimen, K. Ziegler. Nine point-locations representing 68 individuals, most fertilised and gone to seed, with some plants pulled up (K. Ziegler pers. obs.). This indicates a significant proliferation of the original population (1a). 20 Dec. 2018, no specimen, A. Williams. 500 ± 110 individuals on west side of Bridport Road, plants predominantly located on flat area of road reserve above batter. 50 ± individuals on east side of Bridport Road. Population is approximately 1.1 km north of Boddington Road. Plants hand pulled.
1d	Bridport Road	T: State Growth I: Flinders M: Dorset N: North	17 Dec 2017, no specimen, K. Ziegler. Single plant, seed shedding, hand pulled. 20 Dec. 2018, no specimen, A. Williams Six individuals, hand pulled. Site located west side of Bridport Rd, 730 m north of Boddington Road.
1c & 1d	Bridport Road	T: State Growth I: Flinders M: Dorset N: North	8 Dec. 2019, no specimen, J. Cooper. 58 individuals at sites 1c & 1d. Plants hand pulled. Sites 1c & 1d surveyed together, including area of road reserve between sites. (J. Cooper pers. comm.).
2	"Latrobe, council-maintained waste site"	T: Local government I: Flinders M: Latrobe N: Cradle Coast	12 Nov. 2009, HO559795, P.Tonelli. "In-fill wasteland; introduced grasses and pasture weeds, some low quality prostrate native plants (e.g. *Hibbertia procumbens*) in W end close to collection site. Only a single specimen located [excavated]; an extensive search of the local area failed to locate any others" (from HO559795). Refer to Plate 1.
3	"Spreyton/Tarleton area"	T: Private I: Flinders M: Latrobe N: Cradle Coast	8 Nov. 2016, HO586101, G. Pocknee. "Semi-rural 3-acre block, front weedy lawn – sparsely grassed area with mosses and weeds; 5 plants" (from HO586101). "Still finding the occasional one & destroying" (Tasmanian Native Orchids Facebook page, G. Pocknee, 20 Nov. 2019).
4	Settlers Road, Latrobe	T: Private I: Flinders M: Latrobe N: Cradle Coast	20 Nov. 2019, no specimen, Tasmanian Native Orchids Facebook page, BJ Green.
5a	Parkers Ford Road, Port Sorell	T: Local government I: Flinders M: Latrobe N: Cradle Coast	12 Nov. 2019, no specimen, P. Collier. Roadside verge outside private reserve (Rubicon Sanctuary), road verge kept well slashed through late spring and summer. Single specimen excavated and disposed of (P. Collier pers. comm.).

Table 1 cont. — Collection details of all Tasmanian populations of *Disa bracteata*.

Site No. [1]	Location [2]	Details [3]	Comments
5b	Junction to Squeaking Point Road, Port Sorell	T: Local government I: Flinders M: Latrobe N: Cradle Coast	4 Nov. 2018, no specimen, P. Collier (pers. comm.). Grassy roadside, single clumps (3 flower spikes).
6a	St Louis Drive, Port Sorell	T: Private I: Flinders M: Latrobe N: Cradle Coast	20 Nov. 2019, no specimen, S. & A. Farrelly (via Tasmanian Native Orchids Facebook page). Three plants inside property, pulled out and bagged, left in cupboard and found in mid-2020 – plants had re-sprouted inside bag, now destroyed in wood heater (S. & A. Farrelly pers. comm.).
6b	St Louis Drive, Port Sorell	T: Local government I: Flinders M: Latrobe N: Cradle Coast	3 Jan. 2020, no specimen, P. Tonelli (via Tasmanian Native Orchids Facebook page). "Whilst collecting dry grass heads (on road side) for my finches in St Louis Drive, Port Sorell, I spotted a fruiting flower head of the dreaded/invasive *Disa bracteata* a species Orchid originally from South Africa ..then went on to dig out and destroy a dozen + there must be more I missed!" and "to say there was an 'invasion' would be an understatement! They were all along the 'nature strip' on both sides, many have been mown off" (P. Tonelli pers. comm.).
7	"Badger Head Road, N side, E of power pole T6912761A 229117"	T: Local government I: Flinders M: West Tamar N: Cradle Coast	4 Nov. 2014, HO581102, M. Wapstra & 13 Oct. 2015, HO583698. "Slashed grassy road verge; 2 in tight clump; both plants were uprooted" (from HO581102). Refer to Plate 2 and Plate 3. Site re-visited c. 1 year later and non-fertile individuals from precisely same patch dug out with spade (M. Wapstra pers. obs.). Site re-visited 7 Jul. 2020 – no signs of re-sprouting (M. Wapstra pers. obs.).
8	Turners Beach (Bass Highway, west of River Forth)	T: State Growth I: Northern Slopes M: Central Coast N: Cradle Coast	21 Jan. 2020, no specimen, C. Broadfield (via Tasmanian Native Orchids Facebook page). "Scattered along the roadside bank. At least 50 but possibly many more" (C. Broadfield pers. comm.).
9	Clerke Plains Road, Spalford	T: Private I: Northern Slopes M: Central Coast N: Cradle Coast	25 Nov. 2019, no specimen, L. Davison (via Tasmanian Native Orchids Facebook page). "only about 3 inches high, first year it's come up. In sand trucked in to my place from Sassafras about 10 to 12 years ago" (L. Davison pers. comm. 25 Nov. 2019) & "it hasn't come back up yet and last year was the first year" (L. Davison pers. comm. 7 Aug. 2020).
10	"S side of Bass Highway" [between Penguin and Sulphur Creek]	T: State Growth I: Northern Slopes M: Central Coast N: Cradle Coast	8 Nov. 2011, HO564548, S. Casey. "Less than 5 plants were observed; on top of batter with mainly introduced grasses, but with a few native herbs and orchids" (from HO564548). 7 Mar. 2016, HO583720, M. Wapstra. "Grass and weed infested highway batter and flat rise; all individuals excavated with spade" (from HO583720). Approximately 188 individuals were observed along ca. 200 m of the highway verge, slope and flat (M. Wapstra pers. obs.). Site re-assessed on 31 Oct. 2017 by M. Wapstra and most plants marked (all in late bud to very early flower), which was followed by herbicide application on 13 Nov. 2017 (S. Radford pers. comm.). On 26 Feb. 2018, all plants appeared to be dead, but several had formed capsules (M. Wapstra pers. obs.). Refer to Plate 3 and Plate 5. On 7 Nov. 2019, the site was re-assessed. Only 47 individuals were detected, all hand-pulled (M. Wapstra pers. comm.). Weed contractor has been advised and has been requested to visit site at least twice yearly in early-mid Oct. and early to mid Nov. (S. Leighton, State Growth, pers. comm.).

Table 1 cont. — Collection details of all Tasmanian populations of *Disa bracteata*.

Site No. [1]	Location [2]	Details [3]	Comments
11	Old Stanley Road West, Smithton	T: Private I: King M: Circular Head N: Cradle Coast	Sep. 2018, no specimen, Allison Smith & Garth Smith (via Tasmanian Native Orchids Facebook page). "I photographed it on 11/11/2018. Allison first spotted it about 2 or 3 weeks before I posted it in the FB orchid page asking for ID. So she first spotted it approximately the last week of September. We only saw one that year, and that was the same one, that after discussion with you, Allison bagged and monitored, and saw it try to keep growing. The next year (Nov 2019) we monitored the spot and saw nothing in that spot. We monitored it quite regularly as there are T. pauciflora in the near vicinity that I was keeping an eye on to photograph. We will monitor it and the immediate surrounds again this year and in subsequent years. The spot it was growing is remnant coastal dune from when the sea level was a lot higher" (G. Smith pers. comm.).
12	Musselroe area	T: Private I: Flinders M: Dorset N: North	12 Nov. 2013, no specimen, G. Daniels. Re-visited mid-November 2015, with intent to excavate single plant originally observed, but could not be re-found (G. Daniels per. obs.). Refer to Plate 4.
13	Orchard Avenue, Huonville	T: Private I: Southern Ranges M: Huon Valley N: South	20 Nov. 2019, iNaturalist, M. Storer. "29 individual plants. Dug out (with tubers) on 9/12/2019".

[1] Site no. cross-references to Fig. 2.
[2] Location name in " " as per HO record.
[3] T – Tenure; I – Interim Biogeographic Regionalisation for Australia (IBRA) Region; M – Municipality; N – Natural Resource Management Region.

PLATE 4 — Habitat of *Disa bracteata* at Musselroe. (Image: G. Daniels)

PLATE 5 — Habitat of *Disa bracteata* near Burnie on Bass Highway, with several individuals gone to seed in the foreground, circled. (Image: M. Wapstra)

RESULTS

The first record of *D. bracteata* in Tasmania was in 2005 (fig. 2, table 1), 61 years after it was first detected in Western Australia in 1944. Since then, it has been reported from several additional Tasmanian sites (fig. 2, table 1).

The species is now known from all three Natural Resource Management (NRM) regions; the Dorset, Latrobe, West Tamar, Central Coast, Circular Head and Huon Valley municipal areas; and the Flinders, Northern Slopes, King and Southern Ranges IBRA regions (defined in Environment Australia 2000).

The species has a linear range in Tasmania of ca. 255 km (from Smithton to Musselroe) or ca. 190 km (Smithton to Huonville). Until the discovery of the species in Huonville, *D. bracteata* had a predominantly near-coastal distribution in northern Tasmania. Within Tasmania, *D. bracteata* has been collected from disturbed sites (e.g. waste ground around Latrobe), roadside verges (Badger Head Road, Parkers Ford Road, Bridport Road, Bass Highway), rough pasture (Musselroe), and urban-rural living habitats (Spreyton, Port Sorell, Huonville). The verges of several road sites supporting the species are frequently mown/slashed, meaning that the species may have gone undetected for a period, and this is a likely mechanism for localised dispersal.

DISCUSSION

D. bracteata has made a progressive easterly 'march' across Australia since first being detected in Western Australia. Once in Victoria, evidence indicates it has freely spread through that state, and the arrival of the species in Tasmania seemed almost inevitable. Multiple easterly incursions from Western Australia into eastern states may have occurred, although this is conjecture. While the arrival in Tasmania is a relatively recent event, it has not taken long for the species to become widespread across the north coast, and more recently further afield in southern Tasmania.

Due to its early phase of establishment, *D. bracteata* is not perceived to be causing significant negative impacts in Tasmania at this time. In other states, the species has spread rapidly and covered large areas of extent (geographic range) and areas of occupancy (has colonised significant tracts of land). On mainland Australia, the species is a recognised threat to several nationally threatened orchid species (Commonwealth of Australia 2018), for example, *Thelymitra matthewsii* Cheeseman (Duncan 2010). In Tasmania, several sites with *D. bracteata* are close to habitats supporting threatened orchid species and weed invasion is already a recognised threat to Tasmania's native orchids (TSS 2017).

The species is accepted as being fully naturalised in Tasmania (de Salas & Baker 2019). Large parts of Tasmania are climatically suitable, and it is hoped that the apparent lack of records for most of the state represents a genuine absence rather than the species being overlooked. We postulate that there is a genuine risk of *D. bracteata* spreading further in Tasmania over the coming decades. Understanding and predicting biological invasion processes is a valuable tool to anticipate ecological, economic and social impacts, and in some cases to enact fast response actions for biodiversity conservation (e.g. Pertierra *et al.* 2016, Pertierra *et al.* 2017). Konowalik and Kolanowska (2018) undertook ecological niche modelling on *D. bracteata*. They found that most of the accessible areas are already occupied by this species, but future expansion will continue based on different climate change scenarios, with further expansion predicted especially in eastern Australia and eastern Tasmania.

The future spread of *D. bracteata* in Tasmania is likely to be into primary production areas, such as grazing/cropping land and possibly commercial forestry plantations (where it occurs in other states), and parts of the formal conservation reserve system. Of most concern is that three of the known sites are close to conservation areas (Musselroe Bay Conservation Area, Rubicon Sanctuary private reserve and Narawntapu National Park). Unlike many native orchid species, *Disa bracteata* has less specific fungal associations (Bonnardeaux *et al.* 2007) and this may facilitate its weed-like colonisation of disturbed sites (Grant & Koch 2003, Collins *et al.* 2005, De Long *et al.* 2013). Climate change may increase the availability of climatically suitable areas for invasion in Tasmania, particularly at higher elevations. However, even with long-term change, the risk of expansion into the higher rainfall parts of the state, such as the extensive southwest Tasmanian Wilderness World Heritage Area is probably low. Globally non-indigenous orchids appear to present a relatively low risk of impact on natural processes but some localised impacts are recognised (Recart *et al.* 2013).

To date, detections of *D. bracteata* have all been serendipitous, and a result of vigilant observers or during ecological assessments for development proposals (e.g., road widening projects). For most of the year, the species is undetectable, surviving as underground tubers buried below dense grass (plate 2, plate 3). While the leaves are distinctive, a small patch would be easily overlooked or mistaken for other weeds such as young plants of the common and widespread *Tragopogon porrifolius* L. (salsify). It is only once the flowering spike emerges that is more easily detected (and then only usually if the surrounding vegetation has been mown). Targeted surveys of potential habitat (mainly road verges in Tasmania) would be resource-hungry, likely to be 'hit and miss' due to seasonal variations in population emergence and abundance as well as great variability in detectability due to mowing/slashing/herbicide regime, and even then would possibly require complex traffic management to facilitate surveys.

Disa bracteata may warrant listing as declared under the provisions of the Tasmanian *Weed Management Act 1999* as it may have an adverse impact on natural resources and maintenance of indigenous ecological processes in Tasmania. If listed as a declared species on the Tasmanian *Weed Management Act 1999*, Zone A is the classification most applicable to *D. bracteata* for all municipalities. This would mean eradication is the key objective, which we believe should be the short- and long-term management

objective in Tasmania. Efforts to eradicate the species from Latrobe, Bridport Road, Badger Head Road and Parkers Ford Road have been implemented (all by manual excavation of whole plants including tubers and roots). However, the species was re-detected the year after the first excavation of tubers from the Badger Head Road site (M. Wapstra per. obs.). The status of the population near Bridport (the site of original detection of the species in 2005) was uncertain for many years, until observed again in 2016; annual control commenced with its rediscovery (as well as new observations of local sub-populations) but will need to continue for several years after over 500 plants were observed in one season (following excavation efforts the previous year). Despite apparent eradication from the Latrobe site at the time of detection, the species was re-found in the general region (Spreyton) in subsequent years, suggesting further populations may have gone undetected and that propagule pressure from external sources (such as vehicles arriving on mainland ferry services) may result in continual reintroductions at suitable locations. Searches for the species at the Musselroe site in 2015 failed to detect it, possibly meaning it is now absent from there, although no intervention has occurred and the prolonged absence at Bridport after the initial detection suggests that when local populations are establishing the species may not be detectable every year. The population along the Bass Highway near Burnie was manually removed in November 2017 and will continue to be monitored (S. Radford pers. comm.). Treatment at this site has already reduced the number of individuals by more than 75% (M. Wapstra pers. obs.). The distribution of populations in the Port Sorell area suggest that roadside slashing and residential development is actively encouraging the spread of the species. This means that while the long-term management objective should ideally be eradication, in practice this may become containment within the intent of the Tasmanian *Weed Management Act 1999*.

While the recent spread of the species appears to indicate an almost inevitable slow march of *D. bracteata* across suitable parts of Tasmania, it has been effectively eradicated from several sites by early intervention. This provides hope that, with continued vigilance and active management, *D. bracteata* may remain widespread but only as a sparingly naturalised species.

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REFERENCES

Ackerman, J. 2007: Invasive orchids: weeds we hate to love? *Lankesteriana* **7(1–2):** 19–21.

ALA (Atlas of Living Australia) 2020: *Occurrence records*, https://biocache.ala.org.au/occurrences/search?q=lsid%3Ahttps%3A%2F%2Fid.biodiversity.org.au%2Fname%2Fapni%2F190752 (accessed 19 August 2020).

AVH (Australasian Virtual Herbarium) 2020: *Occurrence records*, https://avh.ala.org.au/occurrences/search?q=lsid%3Ahttps%3A%2F%2Fid.biodiversity.org.au%2Fname%2Fapni%2F190752&qc=data_hub_uid%3Adh9 (accessed 19 August 2020).

Bonnardeaux, Y., Brundrett, M., Batty, A., Dixon, K., Koch, J. & Sivasithamparam, K. 2007: Diversity of mycorrhizal fungi of terrestrial orchids: compatibility webs, brief encounters, lasting relationships and alien invasions. *Mycological Research* **111:** 51–61.

Breitwieser, I., Brownsey, P.J., Heenan, P.B., Nelson, W.A. & Wilton, A.D. (eds) 2018: Flora of New Zealand Online – Taxon Profiles, http://www.nzflora.info/factsheet/Taxon/Orchidaceae.html (accessed 30 March 2018).

Chen, X., Liu, Z., Zhu, G., Lang, K., Ji, Z., Luo, Y., Jin ,X., Cribb, P.J., Wood, J.J., Gale, S.W., Ormerod, P., Vermeulen, J.J., Wood, H.P., Clayton, D. & Bell, A. 2009: Orchidaceae. *In* Wu, Z.Y, Raven, P.H. & Hong, D.Y. (eds): *Flora of China. Vol. 25 (Orchidaceae)*. Science Press, Beijing & Missouri Botanical Garden Press: St Louis: 584 pp.

Clements, M. & Jones, D.L. 2008: *Australian Orchid Name Index* (13/6/2008), http://www.anbg.gov.au/cpbr/cd-keys/orchidkey/Aust-Orch-Name-Index-08-06-13.pdf, (accessed 30 March 2018).

Collins, M., Koch, J., Brundrett, M. & Sivasithamparam, K. 2005: Recovery of terrestrial orchids in the post-mining landscape. *Selbyana* **26(1/2):** 255–264.

Commonwealth of Australia 2018: *Species Profile and Threats Database*. Australian Government, Department of the Environment and Energy, http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl. (accessed 19 August 2020).

Conran, J., Maciunas, E. & Maciunas, K. 2011: *Serapias lingua* L. (tongue orchid): naturalised in the Adelaide Hills, South Australia – caveat cultivator? *The Orchadian* **16(12):** 556–561.

De Long, J.R., Swarts, N.D., Dixon, K.W. & Egerton-Warburton, L.M. 2013: Mycorrhizal preference promotes habitat invasion by a native Australian orchid: *Microtis media*. *Annals of Botany* **111:** 409–418.

de Salas, M.F. & Baker, M.L. 2019: *A Census of the Vascular Plants of Tasmania, including Macquarie Island*. Tasmanian Herbarium, Hobart: 156 pp.

DPIPWE (Department of Primary Industries, Parks, Water & Environment) 2020: *Natural Values Atlas*, www.naturalvaluesatlas.tas.gov.au (accessed 8 August 2020).

Duncan, M. 2010: *National Recovery Plan for the Spiral Sun Orchid* Thelymitra matthewsii. Department of Sustainability & Environment, Melbourne: 11 pp.

Environment Australia 2000: *Revision of the Interim Biogeographic Regionalisation for Australia (IBRA) and Development of Version 5.1 – Summary Report*. Department of Environment and Heritage, Canberra: 36 pp.

Gardner, R.O. & de Lange, P.J. 1996: Naturalised plants in New Zealand: new or noteworthy records. *Auckland Botanical Society Journal* **51(2):** 74–77.

Goldblatt, P. & Manning, J. 2000: *Cape Plants: A conspectus of the Cape flora of South Africa, (Strelitzia 9)*. National Botanic Institute of South Africa, Pretoria and Missouri Botanical Garden Press, St Louis: 744 pp.

Grant, C.D. & Koch, J. 2003: Orchid species succession in rehabilitated bauxite mines in Western Australia. *Australian Journal of Botany* **51:** 453–457.

Howell, C. & Sawyer, J.W.D. 2006: *New Zealand Naturalised Vascular Plant Checklist*. New Zealand Plant Conservation Network, Wellington: 60 pp.

Jones, D.L. 2006: *A Complete Guide to Native Orchids of Australia including the Island Territories*. Reed New Holland, Sydney: 496 pp.

Konowalik, K. & Kolanowska, M. 2018: Climatic niche shift and possible future spread of the invasive South African orchid *Disa bracteata* in Australia and adjacent areas. *PeerJ* **6**: e6107 http://doi.org/10.7717/peerj.6107

Leistner, O.A. (ed.) 2000: *Seed plants of Southern Africa: families and genera. (Strelitzia 10)*. National Botanical Institute, Pretoria: 776 pp.

Linder, H.P. 1981: Taxonomic studies in the Disinae. V. A revision of the genus *Monadenia*. *Bothalia* **13(3 & 4):** 339–363.

Mabberley, D.J. 2008: *Mabberley's Plant-Book: A Portable Dictionary of Plants, Their Classification and Uses*. Third edition. Cambridge University Press, Cambridge: 1021 pp.

Pertierra, L.R., Baker, M., Howard, C., Vega, G.C., Olalla-Tarraga, M.A. & Scott, J. 2016: Assessing the invasive risk of two non-native *Agrostis* species on sub-Antarctic Macquarie Island. *Polar Biology* **39(12):** 2361–2371.

Pertierra, L.R., Aragón, P., Shaw, J.D., Bergstrom, D.M., Terauds, A. & Olalla-Tarraga, M.A. 2017: Global thermal niche models of two European grasses show high invasion risks in Antarctica. *Global Change Biology* **23(7):** 2863–2873.

Recart, W., Ackerman, J.A. & Cuevas, A.A. 2013: There goes the neighborhood: apparent competition between invasive and native orchids mediated by a specialist florivorous weevil. *Biological Invasions* **15:** 283–293.

Richardson, F.J., Richardson, R.G. & Shepherd, R.C.H. (2016). *Weeds of the South-East: An Identification Guide for Australia*. R.G. and F.J. Richardson, Meredith: 522 pp.

Rupp, H.M.R. 1947: Two new orchids from Western Australia. *Australian Orchid Review* **11:** 70.

Scott, J.K. & Delfosse, E.S. 1992: Southern African plants naturalised in Australia: a review of weed status and biological control potential. *Plant Protection Quarterly* **7:** 70–80.

Scott, J.K. & Panetta, F.D. 1993: Predicting the Australian weed status of Southern African plants. *Journal of Biogeography* **20(1):** 87–93.

Synge, P.M. (ed.) 1977: *Dictionary of Gardening A Practical and Scientific Encyclopedia of Horticulture*. Second Edition. Oxford University Press, Oxford: 2316 pp.

TSS (Threatened Species Section) 2017: *Threatened Tasmanian Orchids Flora Recovery Plan*. Department of Primary Industries, Parks, Water & Environment, Hobart: 95 pp.

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LONG-TERM MONITORING OF THE THREATENED LESSER GUINEAFLOWER *HIBBERTIA CALYCINA* (DC.) N.A.WAKEF. (DILLENIACEAE) IN TASMANIA

by Perpetua A.M. Turner, Mark Wapstra, Allison Woolley, Katriona Hopkins, Amelia J. Koch and Fred Duncan

(with four text-figures, two plates, one table and five appendices)

Turner, P.A.M., Wapstra, M., Woolley, A., Hopkins, K., Koch, A.J. & Duncan, F. 2020 (9:xii): Long-term monitoring of the threatened lesser guineaflower *Hibbertia calycina* (DC.) N.A.Wakef. (Dilleniaceae) in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 154: 61–82. ISSN: 0080–4703. Forest Practices Authority, 30 Patrick Street, Hobart, Tasmania 7001, Australia (PAMT*, AJK); Discipline of Biological Sciences, School of Natural Sciences, University of Tasmania, Hobart, Tasmania 7001, Australia (PAMT*, AJK); Environmental Consulting Options Tasmania, 28 Suncrest Avenue, Lenah Valley, Tasmania 7008, Australia (MW); Department of Primary Industries, Parks, Water and Environment, 134 Macquarie Street, Hobart, Tasmania 7000, Australia (AW); Stonyford, St Helens, Tasmania 7216, Australia (KH); The Plant Press, 386 Richmond Road, Cambridge, Tasmania 7170, Australia (FD). *Author for correspondence. Email: perpetua.turner@utas.edu.au

This paper describes the distribution of the threatened shrub *Hibbertia calycina* (DC.) N.A.Wakef., a distinctive plant restricted to northeast Tasmania. It compares changes over time in population size and evaluates the species response to disturbance. Results found *H. calycina* distribution is restricted to isolated clumps on highly insolated ridges and steep upper slopes of fine-grained Mathinna-series sedimentary rocks in dry sclerophyll forest dominated by *Eucalyptus sieberi* L.Johnson. Nine populations were documented with an estimated area of occupancy of 0.43 km^2 and area of extent measuring 95 km^2, demonstrating that the current listing of *H. calycina* as vulnerable is appropriate on Tasmania's *Threatened Species Protection Act 1995*. We believe that the distribution of the present population is a result of natural factors (i.e., restricted habitat range and natural fire events) and anthropogenic factors (managed fire regime and illegal firewood cutting). Although frequent fire and roading have the potential to impact populations, *H. calycina* appears to be stable without active management in a landscape of patchy, regular, low severity fire. Our results indicate susceptibility to the soil-borne pathogen *Phytophthora cinnamomi* is likely less problematic than previously postulated, yet more data and research is required before management is changed.
Key Words: fire, forest, *Phytophthora*, management, population, conservation, plantation.

INTRODUCTION

Hibbertia calycina (DC.) N.A.Wakef. (de Salas & Baker 2019) is a non-endemic native vascular plant species listed as vulnerable on the schedules of Tasmania's *Threatened Species Protection Act 1995* but not listed at a national level. *H. calycina* is managed according to the Threatened Species Strategy for Tasmania (DPIPWE 2000), which addresses key threatening processes affecting species identified as having a high priority for conservation (DPIPWE 2000, Commonwealth of Australia 2015). Also found in Victoria, New South Wales and the Australian Capital Territory, the original Tasmanian threatened species listing of *H. calycina* is due to herbarium and early observational data citing a restricted range and localised distribution with little else published on the taxon's response to disturbance. Many of Australia's vascular plants are declared as threatened with extinction (DEE 2020) due to their localised distributions and restricted ranges which make them particularly vulnerable to habitat loss, disease, invasive species and altered disturbance regimes (Dirzo & Raven 2003, Burgman *et al.* 2007, Silcock & Fensham 2018). It is widely recognised that ongoing research and monitoring of changes and trends in the distribution, abundance and response of species to disturbance is important for providing scientific credibility to conserving threatened species (Craigie *et al.* 2018, Legge *et al.* 2018).

H. calycina has an erect habit and can reach heights of up to 1.4 m. Showy yellow flowers of approx. 15 mm diameter are often observed in spring, with a secondary flowering in autumn (Harden & Everett 1990, Toelken 1996, authors pers. obs.) and can occur on very small plants. Despite being distinctive and its area having a strong European history of mining dating back to the 1880s (Bacon 2013), *H. calycina* was not recorded until 1980. Records from 1980–1995 reported five distinct populations with this time period also seeing the discovery of other species: e.g., *Mirbelia oxylobioides* F.Muell from Heathy Hills Reserve in southern Tasmania (Threatened Species Section 2020). It is likely that in Tasmania *H. calycina* was overlooked and we do not believe it was introduced (appendix 1).

The distribution of *H. calycina* coincided with commercial timber harvesting in the 1990s and little was known about the potential impacts to the species of timber harvesting and other associated activities such as roading, fire and disease. To address this, an initial 1995 survey effort aimed at determining population distribution and assessing the abundance of individuals in different populations (Hopkins 1995). Records of *H. calycina* prior to the 1995 survey indicated that it had a restricted distribution in the Scamander area on Tasmania's northeast coast. Known pre-1995 sites, detailed in Hopkins (1995), included Mt Echo, Loila Pinnacle, Pyramid Hill and southern Skyline Tier (sites 3/4/5 Map 19 in Barker (1994)), and a population south of Scamander at McIntyres Ridge (G.E. Williams pers. comm. 1994). The extensive 1995 survey by Hopkins (1995) and subsequent follow-up surveys occurred while timber harvesting was active in *Eucalyptus sieberi* forests.

This paper reports on three surveys undertaken to monitor the population distribution and abundance of *H. calycina* and determine how its population density has changed over 23 years of monitoring, in response to fire and the absence of active management. We discuss threatening processes to the species and provide recommendations for future management.

METHOD

Study area

The study focused on an area of approximately 544 km^2 which encompassed previously known locations of *H. calycina* in northeastern Tasmania (Hopkins 1995). The study was confined to *E. sieberi* forests, which are restricted to northeast lowland and upland slopes (to 500 m elevation), predominantly on Ordovician sediments (Mathinna Beds), Devonian granites and Jurassic dolerite (Grant *et al.* 1995) (fig. 1).

Soils derived from Ordovician sediments (Mathinna Beds) are typically poor in nutrients, shallow and free draining with a poor capacity to hold moisture. These areas are characterised by dramatic sharp ridges with steep slopes leading to deeply incised gullies with ferns and typically contain *E. sieberi* forests that are open dry sclerophyll forest with a secondary canopy of *Allocasuarina littoralis* (Salisb.) L.A.S. Johnson, and a very sparse lower understorey layer of various shrub species including *Pultenaea gunnii* Benth. Descriptions of vegetation can be found in TASVEG (Kitchener & Harris 2013).

The study area has a history of mining (predominantly tin and some gold) dating back to the 1880s (Bacon 2013) with many mineshafts and terracing still evident in the district. Mining is not presently active in the area, although an exploration license is current for Pyramid Hill (Tasmanian Government 2017). Some forestry activities would have been associated with mining; but since 1970 most forestry operations comprised logging of native forest for sawlogs and pulpwood, and conversion of some sites (generally on less insolated slopes) to plantations of

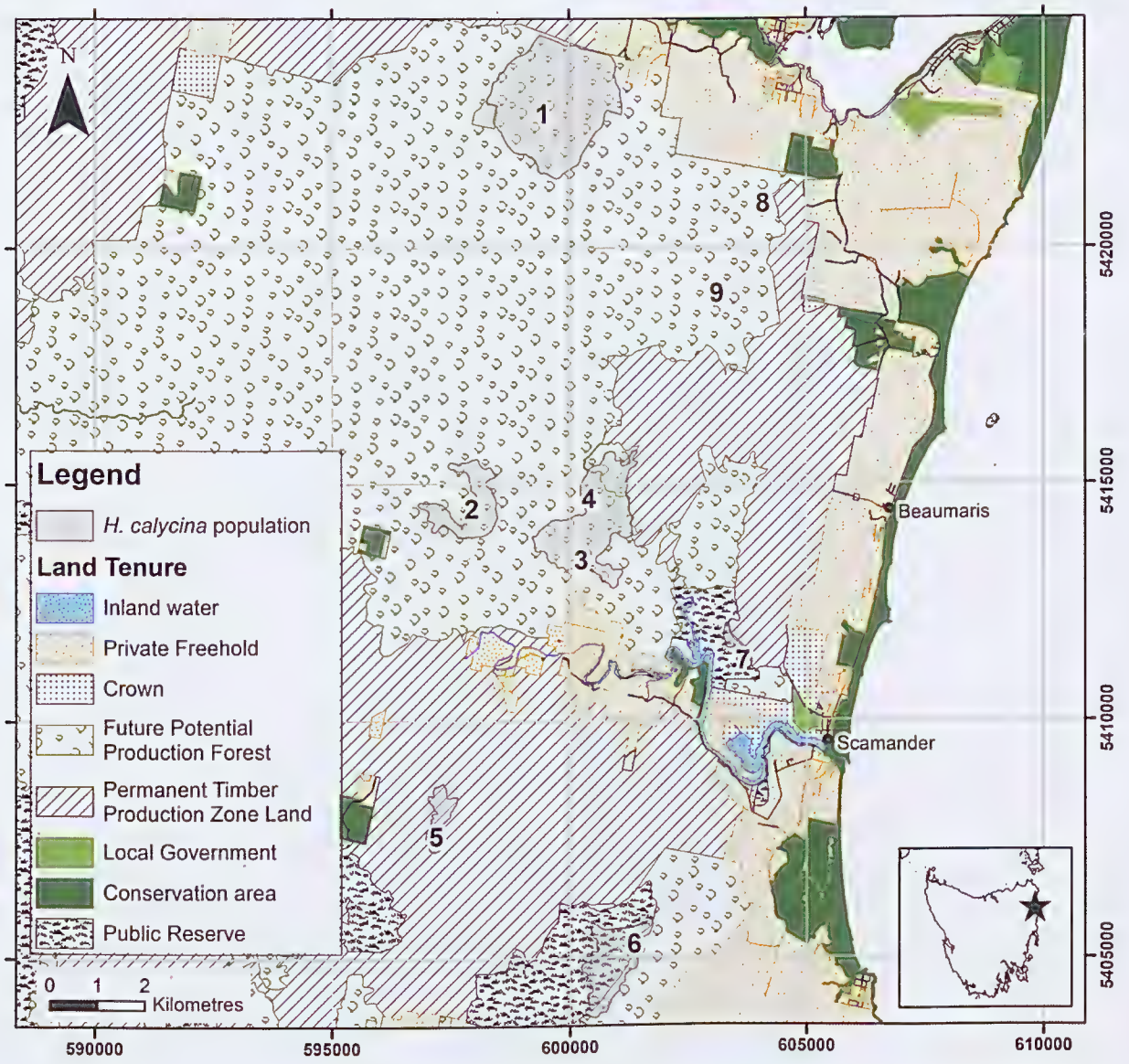

FIG. 1. — *Hibbertia calycina* populations in northeastern Tasmania. Numbers refer to ridgelines (see table 1); 1. Mt Echo, 2. Loila Pinnacle/Wolfram, 3. Pyramid, 4. Orieco, 5. Bolpeys, 6. McIntyres East and McIntyres West, 7. Skyline, 8. Flagstaff, 9. Basin Creek. Inset: location of *H. calycina* in Tasmania.

PLATE 1 — *Hibbertia calycina in situ* (note the very open understorey typical of most sites supporting the species), with inset showing the distinctive (yellow) flowers, and leaf shape and arrangement. Arrow indicates an *H. calycina* plant.

Pinus radiata D.Don. There were few forestry operations in potential *H. calycina* habitat in native forest for years 1995–2018. Invasive species (plant and animal) are not common, except for *P. radiata* wildlings near plantations and the soil pathogen *Phytophthora cinnamomi* that occurs in this area (Schahinger *et al.* 2003).

Northeastern Tasmania has a relatively mild climate with a mean minimum/maximum temperature for January of 12.7/22.1°C and for July of 4.5/13.8°C (Bureau of Meteorology 2018). Rainfall averages 689 mm per annum and rainfall events are irregular; mean monthly rainfall ranges from a low of 45.3 mm (February) to a high of 69.0 mm (April) (Bureau of Meteorology 2018). There are no predominant winter or summer peaks in rainfall although occasional low-pressure systems off Tasmania's east coast can result in intense rainfall events (up to 150 mm in 48 hours; Bureau of Meteorology 2018). Rainfall irregularity means that intense periods of rainfall are often followed by long dry periods (Neyland & Askey-Doran 1996).

Distribution and density of *H. calycina*

The past and present distribution of *H. calycina* was investigated using historical accounts (including published literature), reports, photographs, verification of herbarium specimens, retrieval and verification of unpublished data and mapping. Due to changes in technology there are limitations with previous mapping. However, these data provide useful baselines upon which to reference and compare present data and mapping. Field surveys to determine the extent and size of *H. calycina* populations were undertaken in 1995, with follow-up surveys in 2003/04 and 2017/18 focused on monitoring the 1995 survey populations, and additional discoveries. A 'clump' was defined as a group of *H. calycina* individuals no more than 50 m apart. During these surveys, movement and access were restricted where very steep terrain was encountered and some plants may have been missed.

The first survey, between April and September 1995, surveyed approximately 26 ridgeline systems by vehicle with regular on-foot ground checking (where visibility was low due to topography and/or understorey) for the presence of *H. calycina* (fig. 1). The target species was located on eight of these ridgelines and upper slopes. Sketch maps of *H. calycina* clumps were produced by hand-drawing polygons onto 1:25,000 scale maps. Calculations of boundaries were later checked against maps and aerial photos where available. There was some variability in the detail of the data collected between clumps.

The areas identified as having *H. calycina* in the 1995 sketch maps were re-surveyed in October 2003 and January 2004, apart from a portion of one ridgeline which had been burnt (appendix 2d: Oreico36). One new ridgeline was surveyed due to anecdotal information (Flagstaff). Again, sketch maps of the nine known ridgeline populations were drawn and later digitised into a Geographical Information System (GIS) in 2017. Detailed data on the abundance of *H. calycina* was collected for some but not all nine clumps.

In November 2017 and February 2018 only eight of the nine known ridgelines were re-surveyed due to logistical constraints. During this survey the location and boundaries of all known *H. calycina* clumps were mapped using GPS techniques, and collection of positional data for individual *H. calycina* was undertaken in November 2017 and April 2018 using a Garmin Etrex handheld GPS unit accurate to 5–15 m. Two operators (PAMT and MW) each moved a GPS handheld unit around a *H. calycina* clump, recording a point for every plant where possible: at some sites where many individuals were present, the final number of plants recorded was an estimate, not an absolute count. Plant height for some clumps were recorded with height data provided in Appendices 3 and 5.

The number of *H. calycina* plants per ridgeline were summed for each survey event and compared. The small number of samples per ridgeline restricted statistical analyses. The size of each *H. calycina* population was visually compared over time, but only a brief overview is

provided in the results. The density of *H. calycina* plants (per hectare) was calculated for each clump in 2017/18. Spatial data were analysed in a GIS database (ArcMap) and Excel spreadsheet.

Site disturbance: *Phytophthora* and fire

For each clump, the year of the most recent fire, fire frequency and mean fire interval were determined from the surrounding area, historical records and local knowledge (e.g., Neyland & Askey-Doran 1996, G. Williamson pers. comm. 2018). Fire frequency was the number of times that fires occurred within a site between 1975 and 2018 (43 years). The mean fire interval for a clump was calculated (when more than one fire was recorded for a site) as the sum of the years between each fire event divided by the number of fire events for that clump. Where only one fire event was recorded, the mean fire interval was unknown. The impact of fire on *H. calycina* was assessed by considering how the density of *H. calycina* related to year of the most recent fire and fire interval. All population analyses were performed within the statistical freeware R v.3.4.1 (R Core Team 2019) with packages ggplot2 (version 3.3.2, Wickham 2016) and dplyr (version 1.0.0, Wickham *et al.* 2020).

The suspected presence of *Phytophthora cinnamomi* was recorded by noting symptoms during the 2003/04 survey if *H. calycina* and/or other susceptible species (indicator species; Schahinger *et al.* 2003) were showing signs of disease (i.e., symptoms including dead plants, dieback, yellowing of foliage) where other resistant plants looked healthy. In 2017/18 two sites were tested for *P. cinnamomi* where *H. calycina* plants with yellowing foliage were identified. Tests were done by collecting 5 cm^3 soil samples from around the roots of three yellowing *H. calycina* individuals and then combining the samples for each site before laboratory processing. Soil was analysed for the presence/absence of *P. cinnamomi* using the methods of Ribeiro (1978).

RESULTS

Distribution

In 2017/18 a total of nine *H. calycina* populations were documented with an estimated 15,267 plants, in an area of occupancy of 0.43 km^2 and area of extent measuring 95 km^2. The data suggest there has been an increase in the number of ridgeline *H. calycina* populations over time; however, this increase may be attributed to improved recording and searching techniques with greater precision over time. The 1995 survey found a total of 33 distinct clumps of *H. calycina* on 8 of the 26 ridgelines surveyed (fig. 1, table 1, appendix 4). Of the 1995 survey clumps, in 2003/04 plants of one Oreico clump were labelled 'extinct', and one clump at Flagstaff was added (fig. 1, table 1, appendix 4). Thus in 2003/04 a ninth ridgeline was added but the number of clumps remained the same (33). The number of clumps increased to 41 across the same nine ridgelines in 2017/18 (table 1, fig. 1). In addition to recording all clumps documented in 2003/04, the 2017/18 survey recorded an additional clump at Basin Creek.

PLATE 2. — *Hibbertia calycina* growing in a road verge at Mt Echo.

Where it was possible to compare, the boundary maps for the three survey periods largely found close agreement in the boundaries of *H. calycina* populations over time. However, some clumps had changed, with some single clumps in 1995 becoming multiple clumps (e.g., Pyramid26–29), some clumps had expanded and combined (e.g., Mt Echo1, Loila Pinnacle/Wolfram5, Loila Pinnacle/Wolfram12, Oreico32, McIntyres East37, table 1, appendix 2), and at 15 clumps the range expanded and plants were observed right up to the road verge (e.g., MtEcho1, pl. 2). Of the four clumps surveyed at Oreico in 1995, plants of one clump (Oreico36 of Hopkins 1995) were noted as extinct in 2017/18 (table 1, appendix 2d). At some clumps where *H. calycina* occurs on a slope, populations appear to extend directly downslope over time, perpendicular to the contour (e.g., Mt Echo1, Pyramid30, Oreico32, Oreico33, appendix 2a, c and d).

Density

There is evidence of an overall increase in the number of *H. calycina* plants over time (fig. 2). In 1995 there was a very rough estimate of 4,500 *H. calycina* plants. In 2003/04 this had increased to over 7000 plants, and the 2017/18 survey recorded a total of 15,267 *H. calycina* plants (table 1), averaging a density of 311 plants/ha in the clumps. However, it is likely that for all surveys the total number of plants is an underestimate; many plants on the larger ridgelines may have been missed and it is likely that in some instances a single logged data point represents more than an individual plant. While very high densities of plants were found in many clumps (table 1), the size of these clumps was typically very small. For clumps over 1 ha in size, the density of *H. calycina* ranged from 89–565 plants/ha (table 1).

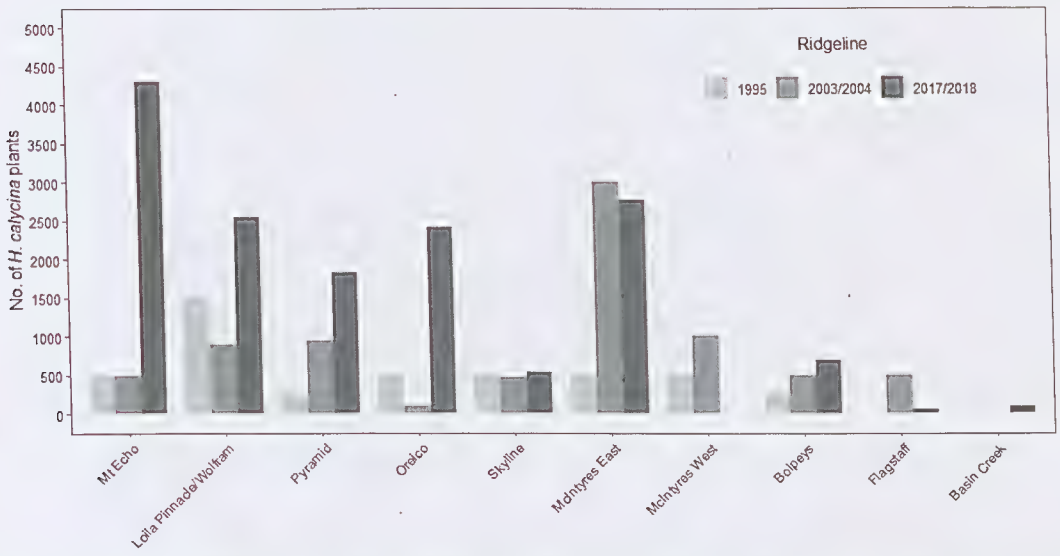

FIG. 2. — Number of *Hibbertia calycina* plants recorded during each survey by ridgeline. Note: some incomplete data, e.g., McIntyres West, Flagstaff and Basin Creek. Maximum value indicated where a range is given (see table 1 for details).

Impact of fire

Signs of historical or recent fire (e.g., fire-hollows or charcoal on trees) were present at all clumps and time since the most recent fire ranged between 2006 and 2017 (table 1). Our results suggest that fire can, but does not always, kill *H. calycina*, and regeneration usually occurs after fire where fire severity is low. Flagstaff40 was visited before and after being burnt in 2017. In June 2019, no individuals were found at the clump location. Four visits after June 2019 and before April 2020 recorded a total of two living plants, presumably from seed, and no re-sprouting plants (MW pers. obs. 2020). Similarly, signs of high severity fire (large, dead trees with fire-hollowed bases) were found at Oreico in 2017/18 and the plants of the Oreico36 clump of the 1995 survey were deemed extinct in 2003/04. Our observations of *H. calycina* populations found mean height of plants varied with time since the most recent fire (e.g., Skyline35, McIntyres37, Pyramid30, appendix 3) and the density of *H. calycina* plants in a clump appears to increase with time since the most recent fire (fig. 3).

The fire frequency varied. For Mt Echo the fire frequency was four fires per ~50 years and for McIntyres West it was two fires per ~50 years (appendix 4). The mean fire interval ranged from four years (Mt Echo3) to 30 years (McIntyres38) with an overall mean of 18 years ± 3 SE (table 1, fig. 4). A longer mean fire interval appears to relate to a higher density of *H. calycina* (fig. 4). Frequent

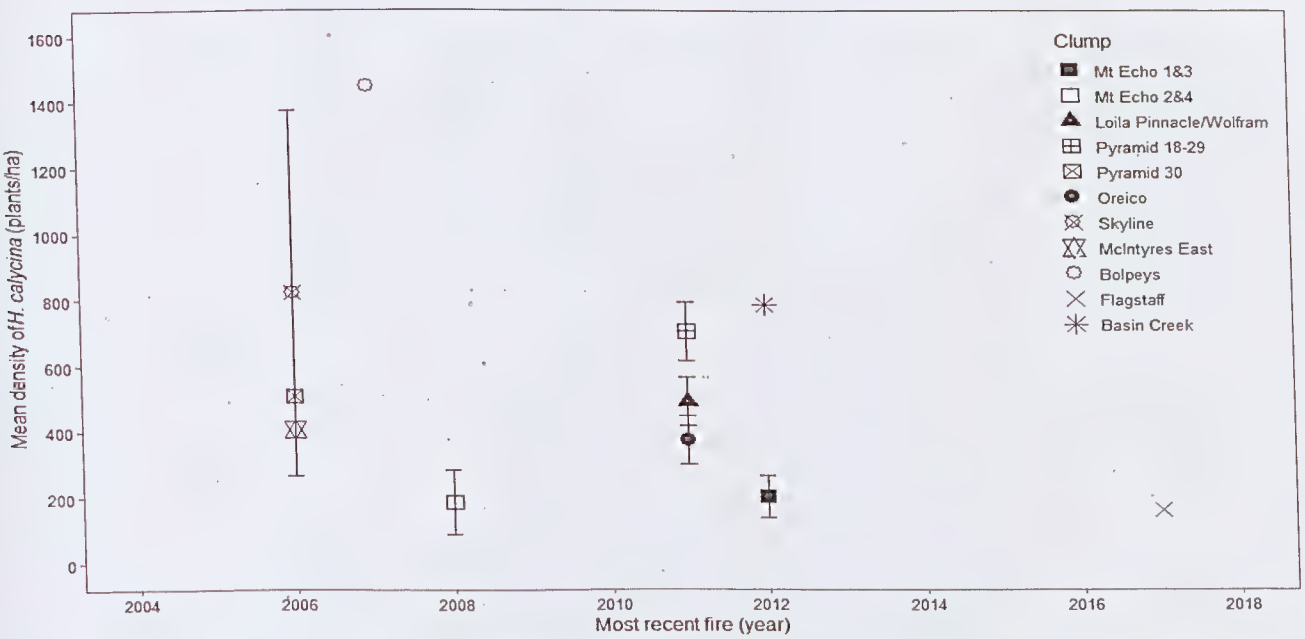

FIG. 3. — Mean density of *Hibbertia calycina* (± SE) (plants/ha) recorded by clump grouped by ridgeline and most recent fire (year), for the 2017/2018 survey. Mt Echo 1&3 (n=2); Mt Echo 2&4 (2); Loila Pinnacle/Wolfram (12); Pyramid (12); Oreico (4); Skyline (2); McIntyres East (1); Bolpeys (1); Flagstaff (1); Basin Creek (1).

TABLE 1 — Population data of *Hibbertia calycina* from all surveys.

Ridgeline	Clump no.	No. of plants			Estimated area (ha)			*H. calycina* plants/ha	Most recent fire (month/ year)	Mean fire interval (years)
	2017/ 2018	1995	2003/ 2004	2017/ 2018[2]	1995	2003/ 2004	2017/ 2018	2017/ 2018		
Mt Echo	1[3,4]			2135			15.45	138	10/2012 (frb)	9
	2[4]			1061			3.78	281	10/2008 (frb)	5
	3[3,4]	**>500**	**250–500**	834	**10**	**no data**	3.14	266	10/2012 (frb)	4
	4[4]			273			3.07	89	10/2008 (frb)	unknown
Loila Pinnacle/ Wolfram	5[3,4]			756			1.61	469.57		
	6[4]		**>100**	262		**no data**	0.43	609.30		**24**
	7[4]			11			0.01	1100.00		
	8[4]			5			0.01	500.00		
	9[4]	**>1000**	**>500 (records of 9 and 50 plants at some sites)**	35	**13**	no data	0.06	583.33	**10/2011 (frb)**	**unknown**
	10[4]			132		10	0.28	471.43		
	11[4]			360		no data	0.99	363.64		
	12[4]			unknown		no data	1.70	NA		
	13[3,4]		**120– 150**	10		**2**	0.12	83.33		
	14[4]			11			0.02	550.00		
	15			52			0.34	152.94		
	16	**<500**	**150**	893	**4**	**3**	1.58	565.19		**24**
	17			21			0.05	420.00		
Pyramid	18		no data	631	3	no data	0.44	1434.09		24
	19[3]			1			0.002	500.00		unknown
	20		**~80**	1		**no data**	0.002	500.00		
	21			55			0.11	500.00		
	22[3]		150– 270	230		3	0.26	884.62		
	23[3]	**~150**		31			0.04	775.00	**10/2011 (frb)**	
	24		**50**	1		**3**	0.002	500.00		
	25			1			0.003	333.33		
	26			92			0.11	836.36		
	27		**98**	10		**no data**	0.02	500.00		
	28			2			0.002	1000.00		
	29		no data	2			0.003	666.67		
	30[3]	<100	~450	775	1	~0.04	1.53	506.54	08/2006 (frb; NE side of road only)	23
Oreico	31		25–50	657		no data	1.32	497.73		27
	extinct[3]		0	0		no data	0.00	NA		NA
	32	**~500**	0	1436	**6**	no data	2.92	491.78	**10/2011 (frb)**	
	33[3]		25–55	101		no data	0.48	210.42		**unknown**
	34		no data	215		no data	0.75	286.67		

TABLE 1 — cont.

Ridgeline	Clump no.	No. of plants			Estimated area (ha)			*H. calycina* plants/ha	Most recent fire (month/ year)	Mean fire interval (years)
	2017/ 2018	1995	2003/ 2004	2017/ 2018[2]	1995	2003/ 2004	2017/ 2018	2017/ 2018		
Skyline	35[3]	**<500**	310	495	**4–5**	3	0.36	1375.00	**12/2006 (esc)**	**13**
	36[3]		167	40		no data	0.15	266.67		
McIntyres (East)	37[4]	>500	>3000	2775	5	no data	6.87	403.93	12/2006 (esc)	unknown
McIntyres (West)[1]	38[4]	~500	>1000	NA	6–7	no data	NA	NA	12/2006 (esc)	30
Bolpeys	39	~250	~500	695	2–3	no data	0.48	1447.92	12/2007 06 (esc)	unknown
Flagstaff	40	-	250–5003	68	-	no data	0.42	161.90	2017 (acc)	13*
Basin Creek	41	-	-	102	-	-	0.13	784.62	05/2012 (frb)	unknown

Bold numbers indicate values apply between horizontal lines in that column.
[1] McIntyres Creek West population was not surveyed in 2017–2018 due to access and funding constraints.
[2] At some sites where many individuals were present, the number of plants logged was an estimate, not an absolute count.
[3] In 2003–2004 survey *Phytophthora cinnamomi* was suspected at these clumps (symptoms noted) and confirmed at Skyline.
[4] Clump included in *Phytophthora* Management Area (Schahinger *et al.* 2003).

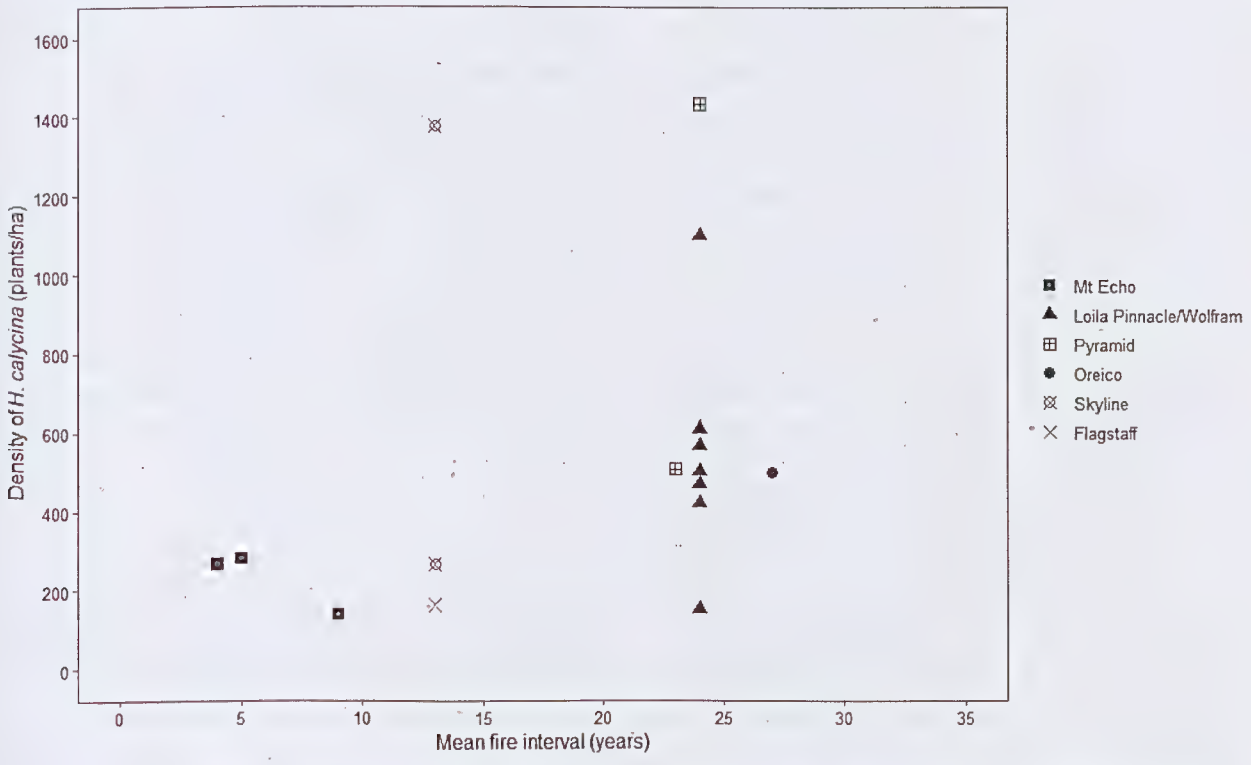

FIG. 4. — Density of *Hibbertia calycina* (plants/ha) by ridgeline recorded during the 2017/2018 survey against the mean fire interval (years) for that clump. See Table 1 for details.

but patchy fires do not appear to significantly impact the area and density of *H. calycina* clumps (e.g., Mt Echo).

Phytophthora cinnamomi

The 1995 survey identified *P. cinnamomi* was already threatening the viability of *H. calycina* clumps. The 2003/04 survey only confirmed *P. cinnamomi* from one site (Skyline), with another 12 sites suspected as being infected by sighting one or many plants showing symptoms of infection (table 1). While in 2017/18 two sites were tested for *P. cinnamomi* (Mt Echo and Loila Pinnacle/Wolfram), both were negative. A search of the *Atlas of Living Australia* (2020) records three sightings of *P. cinnamomi* from sites at which *H. calycina* is present (Mt Echo in 2001 by R. Schahinger record # 526938; Flagstaff in 2003 by A. Woolley record #998942; Skyline in 1973 by C. Palzer # 526097).

DISCUSSION

The present study suggests there has been an increase in the number of individual *H. calycina* plants and clumps between 1995 and 2018, a period when the main disturbance in the area was wildfire. The number of known *H. calycina* clumps was 33 in 1995, and this increased to 41 in 2017/18. This change may in part be attributed to an additional ridgeline with *H. calycina* being located and some 1995 clumps 'splitting' over time (although others joined, and one clump went extinct). It is possible that the increase in number of clumps is also due to greater sampling efforts with time. Regardless of the reason, the results suggest that the number of clumps has remained relatively stable over this time period.

A comparison of the 1995 sketch maps with the 2017/18 GIS maps suggests that many clumps have expanded downslope over time (MW, KH & PAMT pers. obs.). This is possibly a product of heavy rain causing seed to wash downslope, together with suitable temperature and moisture conditions for germination (Schatral *et al.* 1997).

Fire

While the study area has a history of mining and commercial timber harvesting, the only disturbance occurring during the study period was wildfire. The fires in the area have been patchy, meaning there is some variability in the fire history of the different clumps. The results from the current study indicate that severe fire can eliminate populations. Elsewhere, presumably after less severe fire, populations recover. One clump (Flagstaff) was burnt in 2017 and revisited about six months later and there were no signs of plants regenerating until three years after the fire when two seedlings were recorded. Another clump (Oreico36) displayed evidence of high intensity fire in 1995 and the *H. calycina* plants at the site are now considered extinct. In comparison, successful recruitment and spread of plants was evident at long unburnt clumps, such as Mt Echo2 and Mt Echo4 (MW pers. obs.). *H. calycina* does not require burning for regeneration of seed-set and infrequent fire regimes are thought to favour plant recruitment and re-sprouting from lignotubers (Bell *et al.* 1993).

There is little information on the fire regimes of dry sclerophyll *E. sieberi* forests of northeastern Tasmania prior to European settlement (Crawford *et al.* 1962) or for the early years of European colonisation. In more recent times, highly flammable and fire resistant (regenerates post-fire) *E. sieberi* forests are little impacted by a single or repeated understorey fire (Collins 2020). However, repeated short fire intervals (i.e., < 10 years) may cause long-term changes, converting the understorey of forests dominated by epicormic sprouting *E. sieberi* to an alternative state (Pyrke & Marsden-Smedley 2005, Fairman *et al.* 2016, Collins 2020). In the past 30 years Tasmanian *E. sieberi* forests have been subject to a fuel reduction burn program with a recommended seven-year return cycle, to reduce fuel loads and risk to infrastructure (regional towns, mining and commercial timber harvesting operations) (Neyland & Askey-Doran 1996). This is shorter than many of the ecological burning regimes used elsewhere in Australia such as the 20–25 years minimum inter-fire period for box-ironbark forests (Neyland & Askey-Doran 1996, Tolsma *et al.* 2010). Results in the present study suggest *H. calycina* appears to benefit from long (approx. 18-year) fire return cycles and can recover from relatively intense fire via re-sprouting from lignotubers and epicormic growth (Hopkins 1995).

Another disturbance related to fire is the maintenance of vehicular tracks to facilitate access for fire prevention and fuel reduction; these tracks are mainly located on ridgelines. For example, the clump that currently straddles Trout Road (Pyramid30, table 1) is subject to periodic road grading that results in gravel and spoil being pushed downhill over individuals of *H. calycina*. The 1995 and 2003/04 survey notes mentioned that the Mt Echo, Oreico and Pyramid ridgeline clumps were found in areas of disturbance (Hopkins 1995); the 2017/18 survey made similar observations. Whilst plants can be eliminated due to track grading (e.g., Pinnacle/Wolfram13 and Pinnacle/Wolfram14, table 1, MW, KH and PAMT pers. obs.) in the long term, the present study found that *H. calycina* successfully established in areas where soil disturbance from past mining, roading and track creation from timber harvesting or general maintenance has created a possible seedbed suitable for colonisation (pl. 2).

Forestry

In addition to fire, *H. calycina* populations have been subject to other disturbance factors since European settlement. While *E. sieberi* forests were harvested in the 1990s, no commercial timber harvesting has taken place where *H. calycina* occurs in more recent times. Unregulated firewood collection is undertaken extensively across ridgelines and upper slopes in the range of *H. calycina*, with virtually all ridgeline populations of the species dissected by some form of track, now used for firewood collecting.

Phytophthora

Phytophthora cinnamomi is a soil-borne plant pathogen that attacks the root system of susceptible plants and reduces plant health by restricting uptake of water and nutrients. Activities such as recreational vehicles and road maintenance for fire access have the potential to disturb soil and introduce *P. cinnamomi* to populations. In Tasmania, *P. cinnamomi* is widely distributed throughout climatically suitable areas (see Schahinger *et al.* 2003, figs 2 and 3) and the area known to support *H. calycina* is potentially able to support the pathogen (Podger *et al.* 1990, Schahinger *et al.* 2003). The 1995 survey identified *P. cinnamomi* was already threatening the viability of clumps of *H. calycina* (Hopkins 1995). The 2003/04 survey suspected *P. cinnamomi* infection was present at 12 clumps and confirmed on one ridgeline. In 2017/18 there were signs of *P. cinnamomi* infection in the area. *H. calycina* in full sun were observed with leaves yellow in colour on plants that appeared otherwise healthy while plants in the shade displayed no obvious yellowing leaves. On the lower slopes of Mt Echo, *H. calycina* of multiple ages (from seedlings through to plants over 1 m tall) were found growing amongst a 'wave' of dead/dying *Xanthorrhoea australis* R.Br., which is usually a tell-tale sign of *P. cinnamomi*. However, the two tests done in 2017/18 were both negative for *P. cinnamomi*.

H. calycina is known to be susceptible to *P. cinnamomi* because in 1995 live seedlings were found amongst dead and dying *X. australis* at Mt Echo and laboratory tests confirmed death of two plants grown from cuttings died after 81 days, from infection by *P. cinnamomi* in the roots (Barker & Wardlaw 1995). In 2001 *P. cinnamomi* was recorded as a 'sighting' from Mt Echo. The susceptibility of *Hibbertia* species to *P. cinnamomi* varies enormously (Weste & Ashton 1994, Reiter *et al.* 2004). The sample sizes of Barker and Wardlaw (1995) and the present study were small meaning the true susceptibility of *H. calycina* to *P. cinnamomi* is uncertain. Given potential for roading and illegal firewood cutting to facilitate pathogen spread (e.g., Mt Echo, see Barker 1994, Schahinger *et al.* 2003), uncertainty of spread in a changing climate (Commonwealth of Australia 2018), and that *P. cinnamomi* is one of two plant diseases considered at the forefront of conservation concerns in Australia (Burgess *et al.* 2017, Silcock & Fensham 2018), actions to minimise or exclude infection risk by *P. cinnamomi* on *H. calycina* are warranted until larger sample sizes are similarly tested. Sixteen *H. calycina* clumps are found within three *Phytophthora* Management Areas (PMAs) (table 1; Barker *et al.* 1996, Schahinger *et al.* 2003) where there are restrictions on actions such as soil movement (roading) that facilitate pathogen spread.

Conservation status

H. calycina was listed on the Tasmanian *Threatened Species Protection Act 1995*, along with over 400 other plant species, at the commencement of the Act. For many of these plant species, including *H. calycina*, a guide provided brief explanatory information regarding the recommendation to add to the Act (Flora Advisory Committee 1994). The species listing was supported by expert advice prior to Hopkins (1995). This listing is as per criterion 3: vulnerable, criterion B, with the following additional criteria applying: 1: severely fragmented or known to exist at no more than ten locations and, criterion 3.c: extreme fluctuations in number of locations or subpopulations; and, criterion 3.d: extreme fluctuations in number of mature individuals.

The results of the present paper estimated an extent of occurrence of 95[2] km with an area of occupancy of 0.43 km^2, demonstrating that the current listing of *H. calycina* as vulnerable is narrowly acceptable, qualifying under criterion B (extent of occurrence estimated to be less than 2,000 km^2 or area of occupancy estimated to be less than 0.5 km^2) and additional criteria 1 and 3.c. The total population remains relatively small, and restricted, and it could be argued that the population is partially fragmented and occurring at less than 10 locations, meeting criterion B1. Fluctuations are possible where stochastic risk of fire and threatening processes such as *P. cinnamomi* are present (criterion 3.c). Our results show that populations of *H. calycina* are not declining (criterion B2). The present study recorded over 15,000 individuals but did not quantitatively record maturity. Therefore, the requirement to meet vulnerable through criterion 3.d. and criterion C (a decline in the number of mature individuals having a population containing less than 10,000 mature individuals) cannot be confirmed.

With no population decline, and if the majority of individuals are considered to be mature, a qualification as vulnerable is tenuous and *H. calycina* would qualify as rare under Section 15(4) of the Act where the extent of occurrence is less than 80 x 80 km or 2000 km^2; the area of occupancy is not more than 0.5 km^2 (50 hectares), with risks due to threatening processes such as *P. cinnamomi* and fire in a changing climate over the extent of its range. It is possible that *H. calycina* is a species that has always been localised and uncommon in Tasmania, with little loss of localised, preferred habitat. However, as our estimate of individuals did not specifically identify maturity, as a precautionary approach we recommended maintaining the current vulnerable status until another more thorough population estimate noting maturity is undertaken.

We estimate through the 2017/18 data that over 2,500 individuals are securely reserved (Scamander Regional Reserve [Skyline] and German Town Regional Reserve [McIntyres]); a moratorium on production forestry in Future Potential Production Forest was lifted in 2019 (appendix 4). At the time of the first survey in 1995, two ridgeline populations were reserved: Skyline and McIntyres West. The remaining ridgelines occurred in Special Management Zones open to production forestry on public land. Since 1995 no changes to tenure have been made (although some changes to reserve managers have occurred) with the exception of McIntyres East, where west of the ridgeline is reserved (the greater part of the population). Regardless of reservation, the stochastic risk of fire cannot be discounted as previously discussed, and the Tasmanian Forest Practices system would afford

protection should forestry operations be authorised in areas which contain any records of the species.

CONCLUSION

H. calycina is a species highly tolerant of dry, fire-prone environments, appearing to maintain stable population sizes in the face of regular fire events and a lack of active management. Repeated surveys over time found some clumps of plants have gone extinct, likely due to intense fires, indicating protection from frequent, intense fires may be required. Over time, the number of clumps increased, potentially due to greater sampling effort. Whilst *H. calycina* appears to successfully establish on past soil disturbance such as road verges affected by grading, roading to facilitate fire access has the potential to eliminate the species from an area. The susceptibility of the species to infection by *P. cinnamomi* requires further investigation; meanwhile current *Phytophthora* management areas provide some protection of *H. calycina* and associated *P. cinnamomi* susceptible species. Elsewhere within the range of this species, applying hygiene measures to prevent and minimise spread of *P. cinnamomi* and minimising road grading should be implemented. Overall, current *H. calycina* populations are stable. As a precaution, current threatened species status should be maintained until a more thorough assessment of populations, including maturity, is undertaken.

CONFLICT OF INTEREST AND ACKNOWLEDGEMENTS

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REFERENCES

Atlas of Living Australia 2020: *Atlas of Living Australia*, www.ala.org.au (accessed 4 June 2020).

Bacon, C.A. 2013: *A Tasmanian Mining History Timeline.* Tasmanian Geological Survey Record 2013/10. Mineral Resources Tasmania. Department of Infrastructure, Energy and Resources, Hobart. www.mrt.tas.gov.au/mrtdoc/dominfo/download/UR2013_10/UR2013_10.pdf (accessed 7 May 2019).

Barker, P.C.J. 1994: *Phytophthora cinnamomi: The susceptibility and management of selected Tasmanian rare species.* Forestry Tasmania and Australian Nature Conservation Agency. Hobart: 104 pp.

Barker, P.C.J. & Wardlaw, T.J. 1995: Susceptibility of selected Tasmanian rare plants to *Phytophthora cinnamomi*. *Australian Journal of Botany* **43:** 379–386.

Barker, P.C.J., Wardlaw, T.J. & Brown, M.J. 1996: Selection and design of *Phytophthora* management areas for the conservation of threatened flora in Tasmania. *Biological Conservation* **76:** 187–193.

Bell, T.D., Plummer, J.A. & Taylor, S.K. 1993: Seed germination ecology in south western, Western Australia. *The Botanical Review* **59:** 34–69.

Bureau of Meteorology 2018: *'Average annual, seasonal and monthly rainfall.'* www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp and www.bom.gov.au/jsp/ncc/climate_averages/temperature/index.jsp (accessed 10 May 2019).

Burgess, T.J., Scott, J.K., McDougall, K., Stukely, M.J.C., Crane, C., Dunstan, W.A., Brigg, F., Andjic, V., White, D., Rudman, T., Arentz, F., Noborum, O. & Hardy, G.E.S. 2017: Current and projected global distribution of *Phytophthora cinnamomi*, one of the world's worst plant pathogens. *Global Change Biology* **23:** 1661–1674.

Burgman, M.A., Keith, D., Hopper, S.D., Widyatmoko, D. & Drill, C. 2007: Threat syndromes and conservation of the Australian flora. *Biological Conservation* **134:** 73–82.

Collins, L. 2020: Eucalypt forests dominated by epicormic resprouters are resilient to repeated canopy fires. *Journal of Ecology* **108:** 310–324.

Commonwealth of Australia 2015: *Threatened Species Strategy.* Canberra. www.environment.gov.au/biodiversity/threatened/publications/threatened-species-strategy (accessed 7 May 2019).

Commonwealth of Australia 2018: *Threat abatement plan for disease in natural ecosystems caused by* Phytophthora cinnamomi. www.environment.gov.au/system/files/resources/ee1f3b9f-6e2e-4a01-86f3-6abb167fb443/files/tap-phytophthora-cinnamomi-2018.pdf (accessed 7 May 2019).

Craigie, V., Reynolds, D., Walsh, N., Mueck, S., James, E., Tonkinson, D. & Rudolph, P. 2018: Spiny rice-flower – small, unassuming but with many friends, pp. 43–53. *In* Garnett, S., Latch, P., Lindenmayer, D. & Woinarski, J. (eds): Recovering Australian Threatened Species, CSIRO Publishing, Clayton South: 342 pp.

Crawford, E.C., Ellis, W.F. & Stancombe, G.H. 1962: The diaries of John Helder Wedge, 1824–1835. Royal Society of Tasmania, Hobart: 100 pp.

DEE (Department of Environment & Energy) 2020: *EPBC Act List of Threatened Flora.* www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=flora (accessed 20 January 2020).

de Salas, M.F. & Baker, M.L. 2019: *A Census of the Vascular Plants of Tasmania, including Macquarie Island.* Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Hobart: 156 pp. www.tmag.tas.gov.au/__data/assets/pdf_file/0005/179915/2018_Census_of_Tasmanian_Vascular_Plants.pdf (accessed 7 May 2019).

Dirzo, R. & Raven, P.H. 2003: Global state of biodiversity and loss. *Annual Review of Environmental Resources* **28:** 137–67.

DPIPWE (Department of Primary Industries, Water and Environment) 2000: *Threatened Species Strategy for Tasmania.* Nature Conservation Branch, Department of Primary Industries, Water and Environment, Hobart: 30 pp. https://dpipwe.tas.gov.au/Documents/threatspstrat.pdf (accessed 7 May 2019).

Fairman, T.A., Nitschke, C.R. & Bennett, L.T. 2016: Too much, too soon? A review of the effects of increasing wildfire frequency on tree mortality and regeneration in temperate eucalypt forests. *International Journal of Wildland Fire* **25:** 831–848.

Flora Advisory Committee 1994: Native higher plant taxa which are rare or threatened in Tasmania. Edition 1 Species at Risk, Tasmania. Parks and Wildlife Service, Tasmania, Hobart: 23 pp.

Grant, J., Laffan, M., Hill, R. & Neilsen, W. 1995: Forest Soils of Tasmania. Forestry Tasmania, Hobart: 189 pp.

Harden, G.J. & Everett, J. 1990: Dilleniaceae. 293–303, In Harden, G.J. (ed): *Flora of New South Wales.* University of New South Wales Press Ltd, Sydney: 574 pp.

Hopkins, K. 1995: *The Distribution of* Hibbertia calycina *(Guinea Flower) in the St Helens – Scamander Area.* Report to the Eastern Tiers District. Forestry Tasmania: .. Hobart: 44 pp.

Kitchener, A. & Harris, S. 2013: *From Forest to Fjaeldmark: Descriptions of Tasmania's Vegetation.* Edition 2. Department of Primary Industries, Parks, Water and Environment, Tasmania: 24 pp.

Legge, S., Lindenmayer, D., Robinson, N., Schelle, B., Southwell, D. & Wintle, B. 2018: Monitoring threatened species and ecological communities. CSIRO Publishing, Australia: 480 pp.

Neyland, M. & Askey-Doran, M. 1996: Effects of repeated fires on dry sclerophyll (*E sieberi*) forests in northeast Tasmania. *Records of the Queen Victoria Museum and Art Gallery* **103:** 47–50.

Podger, F.D., Mummery, D.C., Palzer, C.R. & Brown, M.J. 1990: Bioclimatic analysis of the distribution of damage to native plants in Tasmania by *Phytophthora cinnamomi. Australian Journal of Ecology* **15:** 281–289.

Pyrke, A.F. & Marsden-Smedley, J.B. 2005: Fire-attributes categories, fire sensitivity, and flammability of Tasmanian vegetation communities. *Tasforests* **16**: 35–46.

R Core Team. 2019: *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. www.R-project.org/.

Reiter, N., Weste, G. & Guest, D. 2004: The risk of extinction resulting from disease caused by *Phytophthora cinnamomi* to endangered, vulnerable or rare plant species endemic to the Grampians, western Victoria. *Australian Journal of Botany* **52:** 425–433.

Ribeiro O.K. 1978: A source book of the genus Phytophthora. Strauss and Cramer, Vaduz, Germany: 417 pp.

Schahinger, R., Rudman, T. & Wardlaw, T.J. 2003: *Conservation of Tasmanian plant species and communities threatened by* Phytophthora cinnamomi. Strategic Regional Plan for Tasmania Technical Report 03/03. Nature Conservation Branch, Department of Primary Industries, Water and Environment: Hobart. https://dpipwe.tas.gov.au/Documents/Conservation-of-Tas-Plant-Species-Threatened-by-*Phytophthora*.pdf (accessed 7 May 2019).

Schatral, A., Osborne, J.M. & Fox, J.E.D. 1997: Dormancy in seeds of *Hibbertia cuneiformis* and *H. huegelii* (Dilleniaceae). *Australian Journal of Botany* **45:** 1045–1053.

Silcock, J.L. & Fensham, R.J. 2018: Using evidence of decline and extinction risk to identify priority regions, habitats and threats for plant conservation in Australia. *Australian Journal of Botany* **66:** 541–555.

Tasmanian Government 2017: *LISTmap - Land Information System of Tasmania.* Tasmanian Government: Hobart: http://maps.thelist.tas.gov.au/listmap/app/list/map (accessed 7 May 2019).

Threatened Species Section 2020: *Mirbelia oxylobioides* (sandstone bushpea): Species Management Profile for Tasmania's Threatened Species Link. www.threatenedspecieslink.tas.gov.au/Pages/Mirbelia-oxylobioides.aspx. Department of Primary Industries, Parks, Water and Environment, Tasmania (accessed 10 October 2020).

Toelken, H.R. 1996: *Hibbertia. In* Walsh, N.G. & Entwisle, T.J. (eds): *Flora of Victoria Volume 3 Dicotyledons Winteraceae to Myrtaceae.* Inkata Press, Melbourne: 300–313. https://vicflora.rbg.vic.gov.au/flora/key/2245

Tolsma, A., Brown, G. & Cheal, D. 2010: The likely impacts of prescribed fire on the flora and fauna of box-ironbark remnants. *Transactions of the Royal Society of Victoria* **122:** lxxxv–xc.

Weste, G. & Ashton, D.H. 1994: Regeneration and survival of indigenous dry sclerophyll species in the Brisbane Ranges, Victoria, after a *Phytophthora cinnamomi* epidemic. *Australian Journal of Botany* **42:** 239–253.

Wickham, H. 2016: *ggplot2: Elegant Graphics for Data Analysis.* Springer-Verlag, New York: 216 pp.

Wickham, H., François, R., Henry, L. & Müller, K. 2020: *dplyr: A Grammar of Data Manipulation.* R package version 1.0.0. https://CRAN.R-project.org/package=dplyr

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APPENDIX 1

History of *Hibbertia calycina* collections in Tasmania

Background

Hibbertia Andrews is a genus of more than 170 species, distributed mainly in Australia and extending to New Guinea, Madagascar and some Pacific islands (APNI 2019). The number of species recognised in Tasmania has been somewhat fluid, especially in recent years as the taxonomy of some of the species complexes of southeastern Australia are resolved (e.g., Toelken 1998, 2000, 2013). Tasmania currently has eighteen accepted species of *Hibbertia* (de Salas & Baker 2019). One species, *H. basaltica*, is recognised as endemic to the state (Buchanan & Schahinger 2000). Some of the non-endemic species have localised distributions in Tasmania. In Tasmania, they include *H. calycina* (DC.) N.A.Wakef. (de Salas & Baker 2019), which also occurs in Victoria (Willis 1972, Toelken 1996), New South Wales (Harden & Everett 1990), and the Australian Capital Territory (Burbidge & Gray 1970). The recognition in other state floras that '*H. calycina*' also occurred in Tasmania is a relatively recent development. For example, Toelken (1996) in the *Flora of Victoria*'s treatment of *Hibbertia* did not attribute the species to Tasmania, although the current online version now does.

In Tasmania

Hibbertia calycina (plate 1 in the main article) was not included in *The Student's Flora of Tasmania Part 1* (Curtis & Morris 1975), since the Tasmanian Herbarium did not hold any specimens attributable to the species until the early 1980s. That such a distinctive species was apparently overlooked (or at least not collected) for close to two centuries of European occupation is somewhat surprising, especially given focus on the flora of the greater St Helens region in the late 1800s. In 1892 Fitzgerald collected *H. rufa* N.A.Wakef. from the area; this species was not recorded again until 2008, when it was found to be localised but often abundant (Wapstra *et al.* 2011) in heathland north of St Helens. Elsewhere, two species of *Hibbertia*, both distributed around Sydney, also went overlooked, despite 200 years of occupation: *H. spanantha* Toelken & A.F.Rob. is a newly-described species known from three populations totalling 20 plants and listed as Critically Endangered (New South Wales *Threatened Species Conservation Act* 1995, Toelken & Robinson 2015); *H. fumana* Sieber ex Toelken has been recently rediscovered: with a population of 370 plants it is provisionally listed as Critically Endangered (New South Wales *Threatened Species Conservation Act* 1995, Duretto *et al.* 2017).

Prior to the recent submission of a batch of voucher specimens from surveys conducted in 2003/2004 (MW), the Tasmanian Herbarium only held eight sheets of *Hibbertia calycina*, the earliest from 9 Oct. 1980, three from 15 Jun. 1981, one from 8 Aug. 1981, and one each from 19 Oct. 1993, 6 Apr. 1995 and 20 Sep. 1999. The specimens from 1981 were originally labelled "*Hibbertia ?cistiflora*", presumably reflecting the use of a mainland flora to identify the specimens (A. Buchanan pers. comm.), but all subsequent specimens were labelled as '*Hibbertia calycina*'. The Queen Victoria Museum and Art Gallery (QVMAG) also holds five collections of the taxon, two of which are apparent duplicates (both labelled "Upper Scamander Pitts Hill", dated 9 Oct. 1980, and attributed to Mary Cameron), these probably being duplicates of the specimen held at the Tasmanian Herbarium with the same date and location. Of note is that these specimens are labelled "first recording for Tasmania". Other collections held at QVMAG include two from 20 Aug. 1981, attributed to "Forestry Officers" and one from 29 Sep. 1987 (also a Mary Cameron collection).

References

APNI (Australian Plant Name Index) 2019: IBIS database, Centre for Australian National Biodiversity Research, Australian Government, Canberra. www.cpbr.gov.au/cgi-bin/apni (accessed 7 May 2019).

Buchanan, A.M. & Schahinger, R.B. 2005: A new endemic species of *Hibbertia* (Dilleniaceae) from Tasmania. *Muelleria* **22**: 105–109.

Burbidge, N.T. & Gray, M. 1970: *Flora of the Australian Capital Territory*. Australian National University Press, Canberra: 447 pp.

Curtis, W.M. & Morris, D.I. 1975: *The Student's Flora of Tasmania Part 1 Gymnospermae, Angiospermae: Ranunculaceae to Myrtaceae* (Second Edition, 1981 Reprint). Government Printer, Hobart: 240 pp.

de Salas, M.F. & Baker, M.L. 2019: A Census of the Vascular Plants of Tasmania, including Macquarie Island. Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Hobart: 156 pp. www.tmag.tas.gov.au/__data/assets/pdf_file/0005/179915/2018_Census_of_Tasmanian_Vascular_Plants.pdf (accessed 7 May 2019).

Duretto, M.F., Orme, A.E, Rodd, J., Stables, M. & Toelken, H. 2017: *Hibbertia fumana* (Dilleniaceae), a species presumed to be extinct rediscovered in the Sydney region, Australia. *Telopea* **20**: 143–146.

Harden, G.J. & Everett, J. 1990: Dilleniaceae. *In* Harden, G.J. (ed.): *Flora of New South Wales*. University of New South Wales Press Ltd: Sydney: 293–303. https://profiles.ala.org.au/opus/foa/profile/Dilleniaceae

Toelken, H.R. 1996: *Hibbertia. In* Walsh, N.G. & Entwisle, T.J. (eds): *Flora of Victoria Volume 3 Dicotyledons Winteraceae to Myrtaceae*. Inkata Press, Melbourne: 300–313. https://vicflora.rbg.vic.gov.au/flora/key/2245

Toelken, H.R. 1998: Notes on *Hibbertia* (Dilleniaceae) 2. The *H aspera–H empetrifolia* complex. *Journal of the Adelaide Botanic Gardens* **18(2):** 107–160.

Toelken, H.R. 2000: Notes on *Hibbertia* (Dilleniaceae) 3. *H sericea* and associated species. *Journal of the Adelaide Botanic Gardens* **19:** 1–54.

Toelken, H.R. 2013: Notes on *Hibbertia* subg *Hemistemma* (Dilleniaceae) 9. The eastern Australian *H vestita* group, including *H pedunculata* and *H serpyllifolia*. *Journal of the Adelaide Botanic Gardens* **26:** 31–69.

Toelken, H.R. & Robinson, A.F. 2015: Notes on *Hibbertia* (Dilleniaceae) 11. *Hibbertia spanantha*, a new species from the central coast of New South Wales. *Journal of the Adelaide Botanic Gardens* **29:** 11–14.

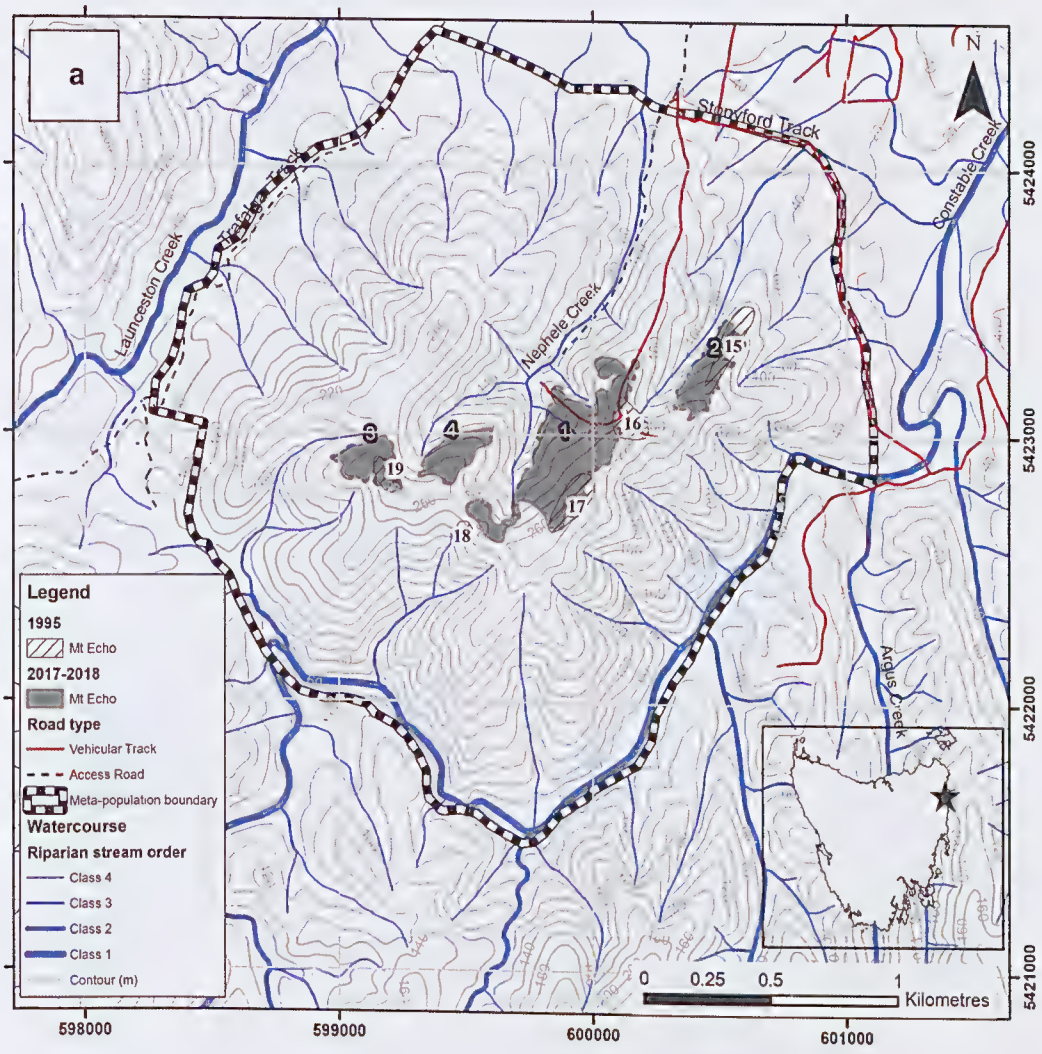
Wapstra, M., French, B., Tyquin, V. & Skabo, R. 2011: From presumed extinct to probably secure? The resurrection and ongoing management of *Hibbertia rufa* (brown guineaflower) in north-east Tasmania. *Tasforests* **19:** 54–70.

Willis, J.H. 1972: A Handbook to Plants in Victoria, Volume II, Dicotyledons. Melbourne University Press, Melbourne: 832.

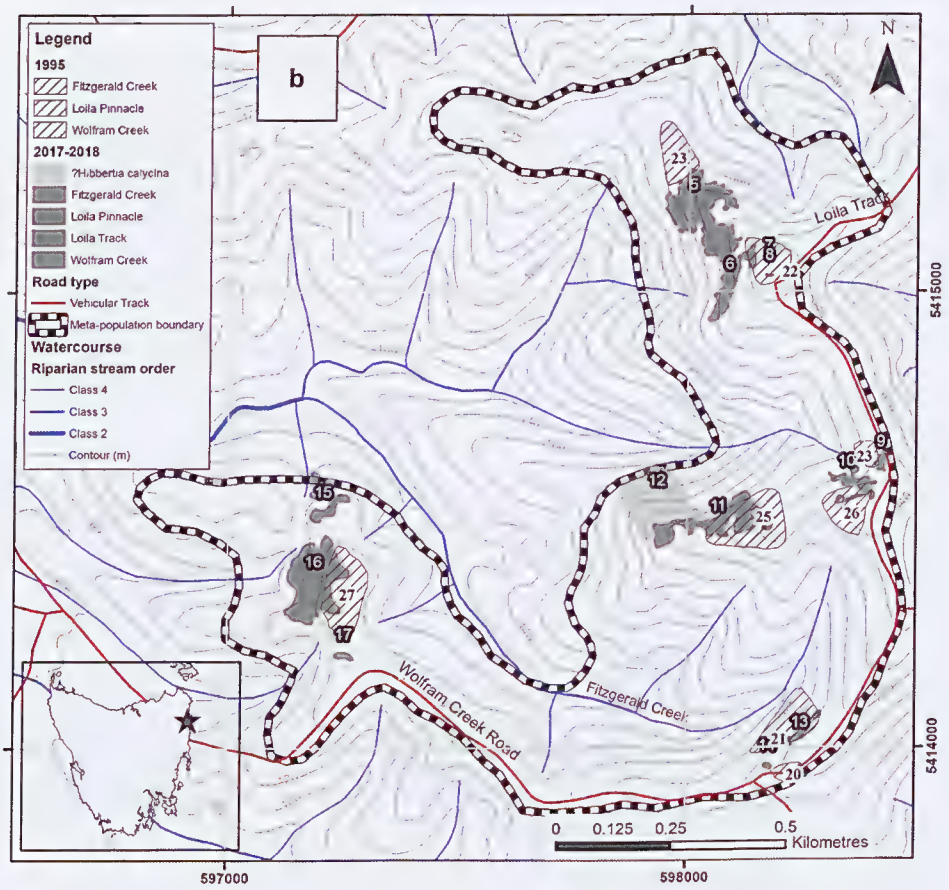
APPENDIX 2

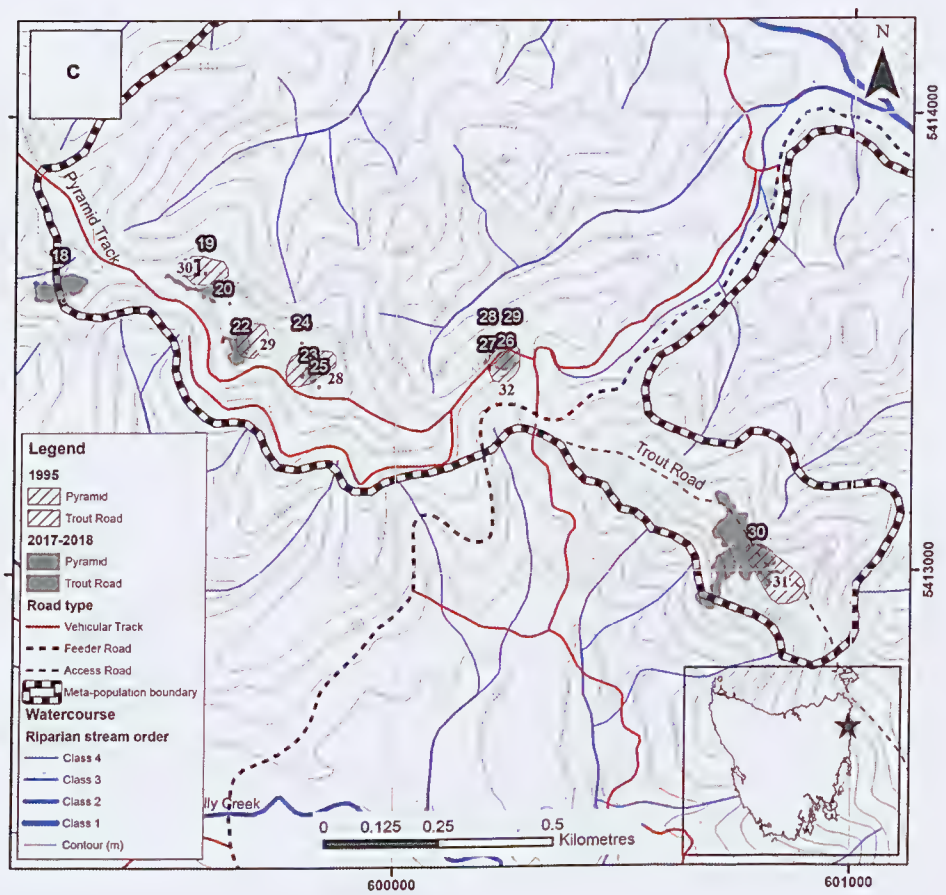
Clumps of *Hibbertia calycina* in northeastern Tasmania.

Clump numbers for 2017/18 and 1995 surveys are shown. (a) Mt Echo, (b) Loila Pinnacle/Wolfram, (c) Pyramid, (d) Oreico, (e) Skyline, (f) McIntyres East and McIntyres West, (g) Bolpeys, (h) Flagstaff, (i) Basin Creek. Inset: Map of Tasmania showing position of all clumps.

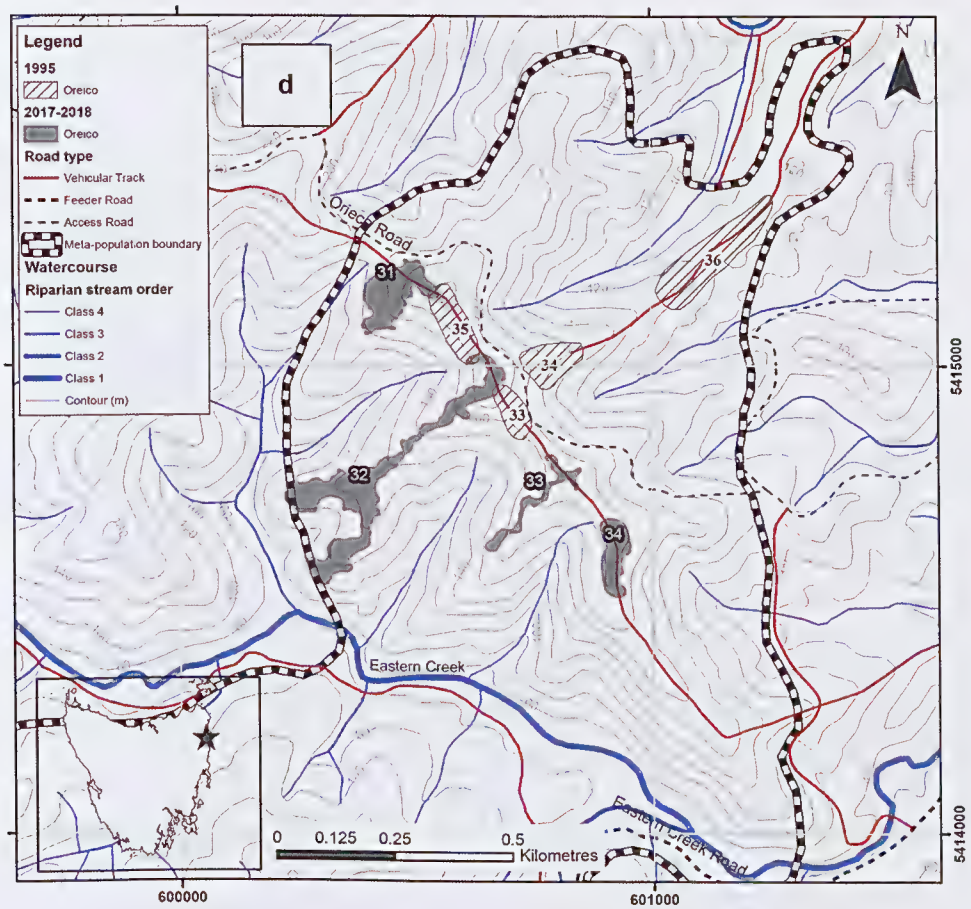


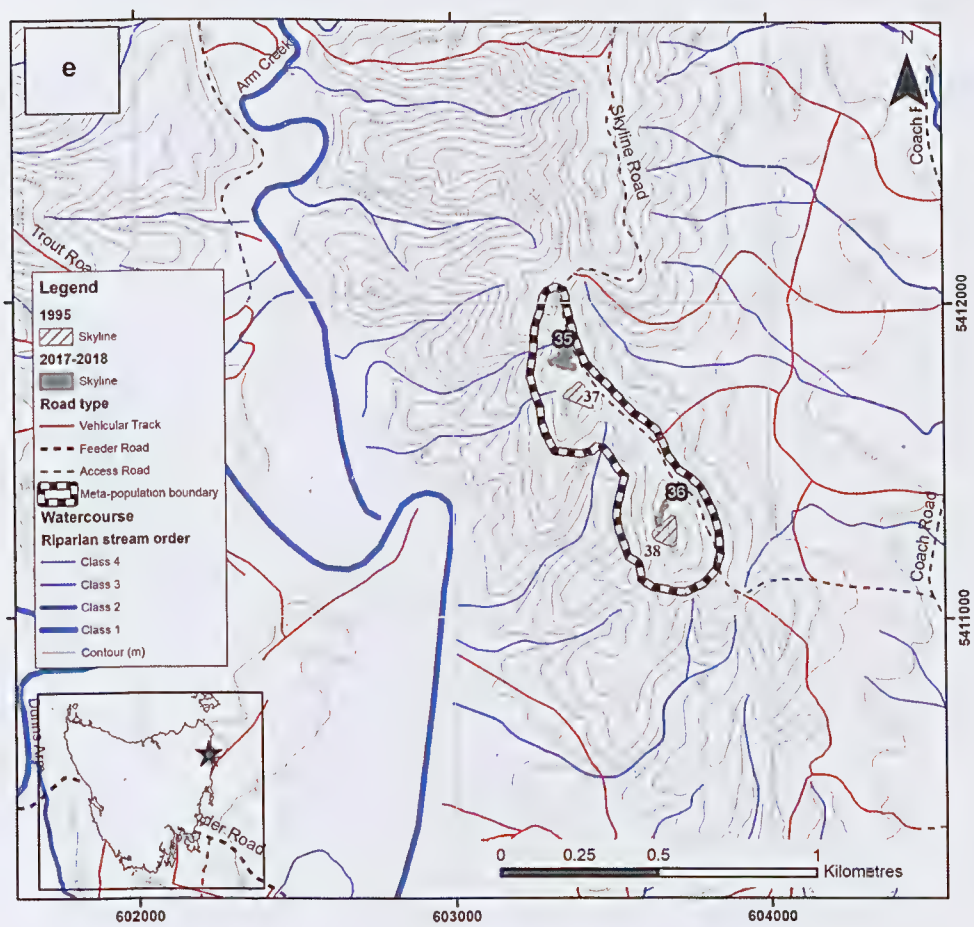
APPENDIX 2 — cont.



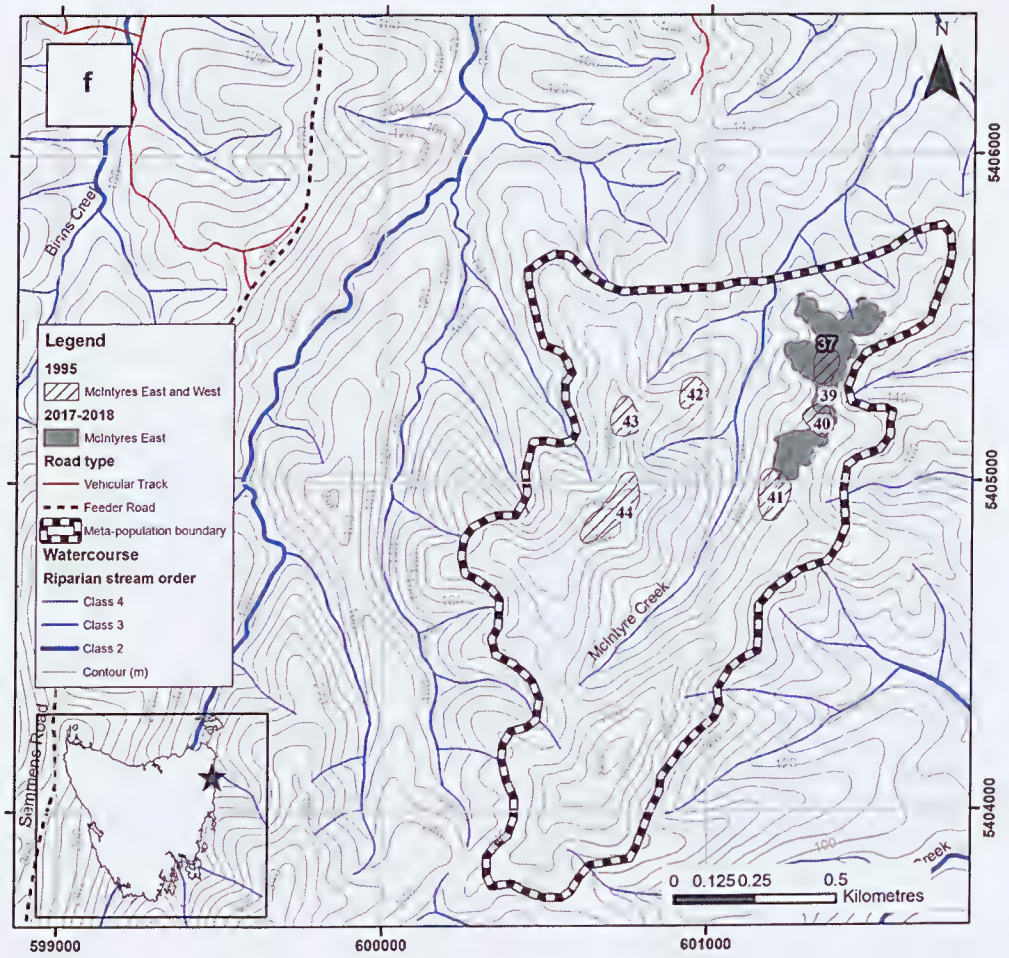


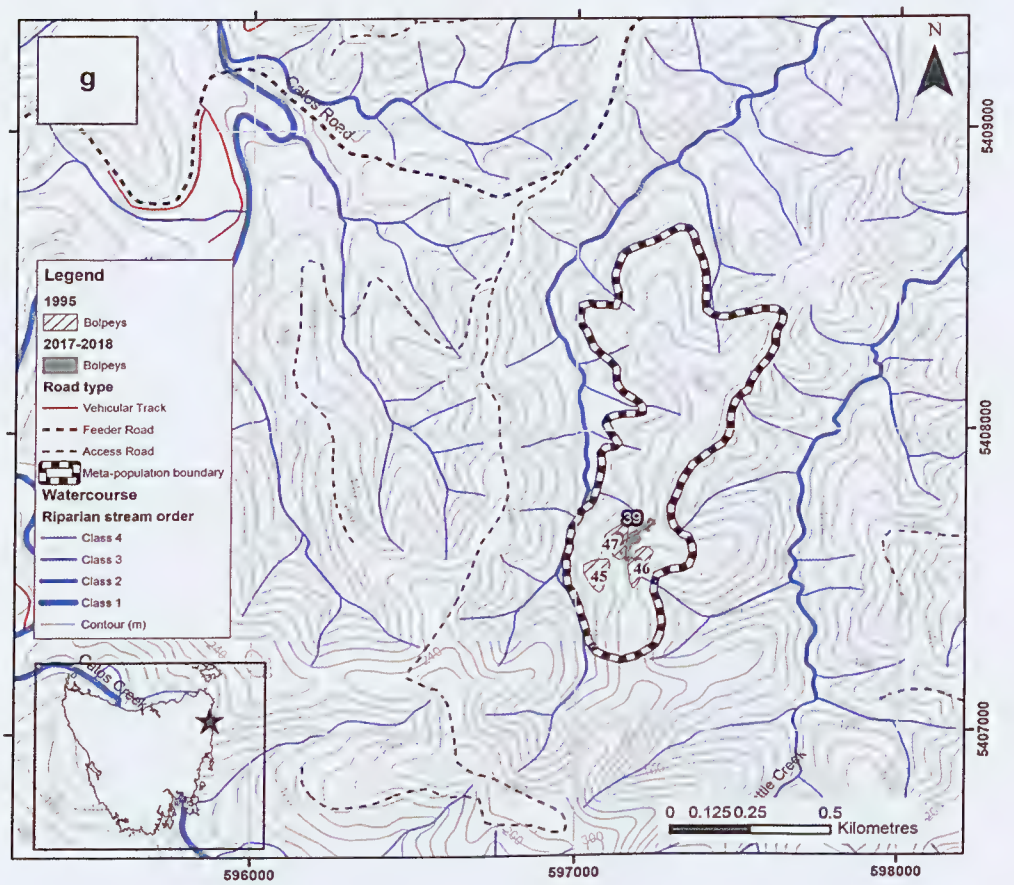
APPENDIX 2 — cont.





APPENDIX 2 — cont.





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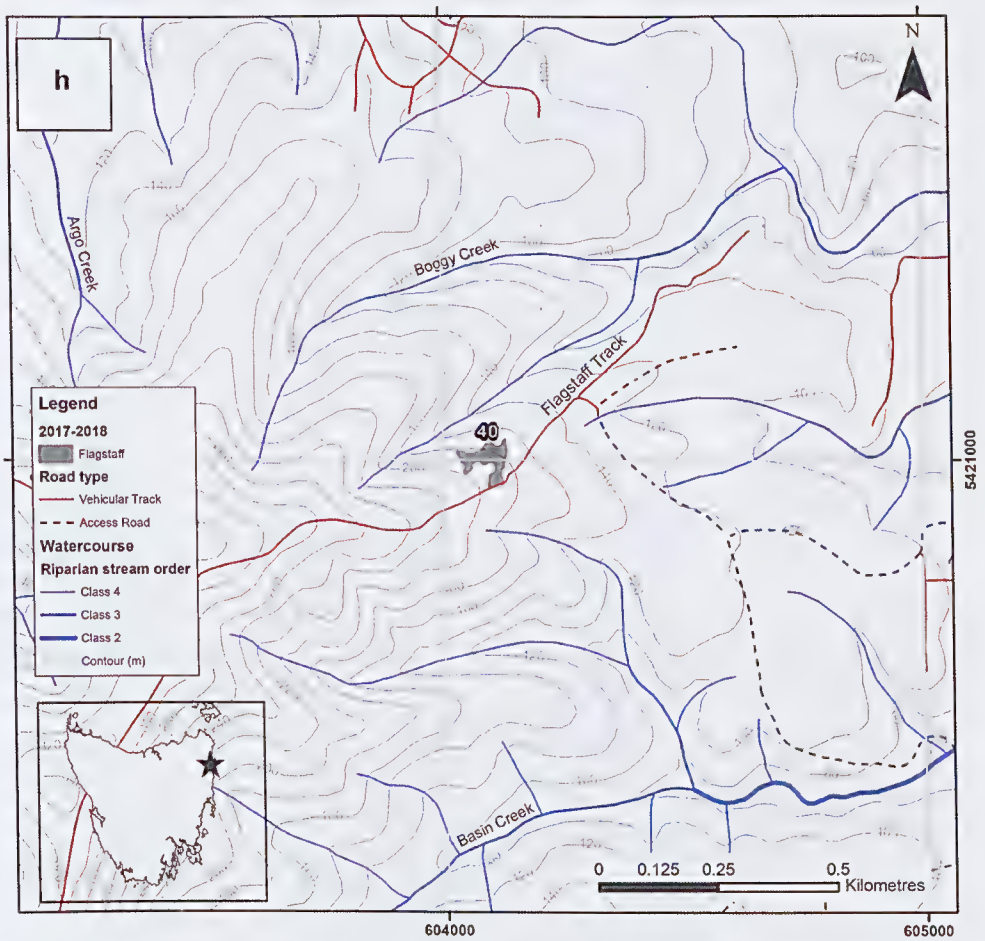
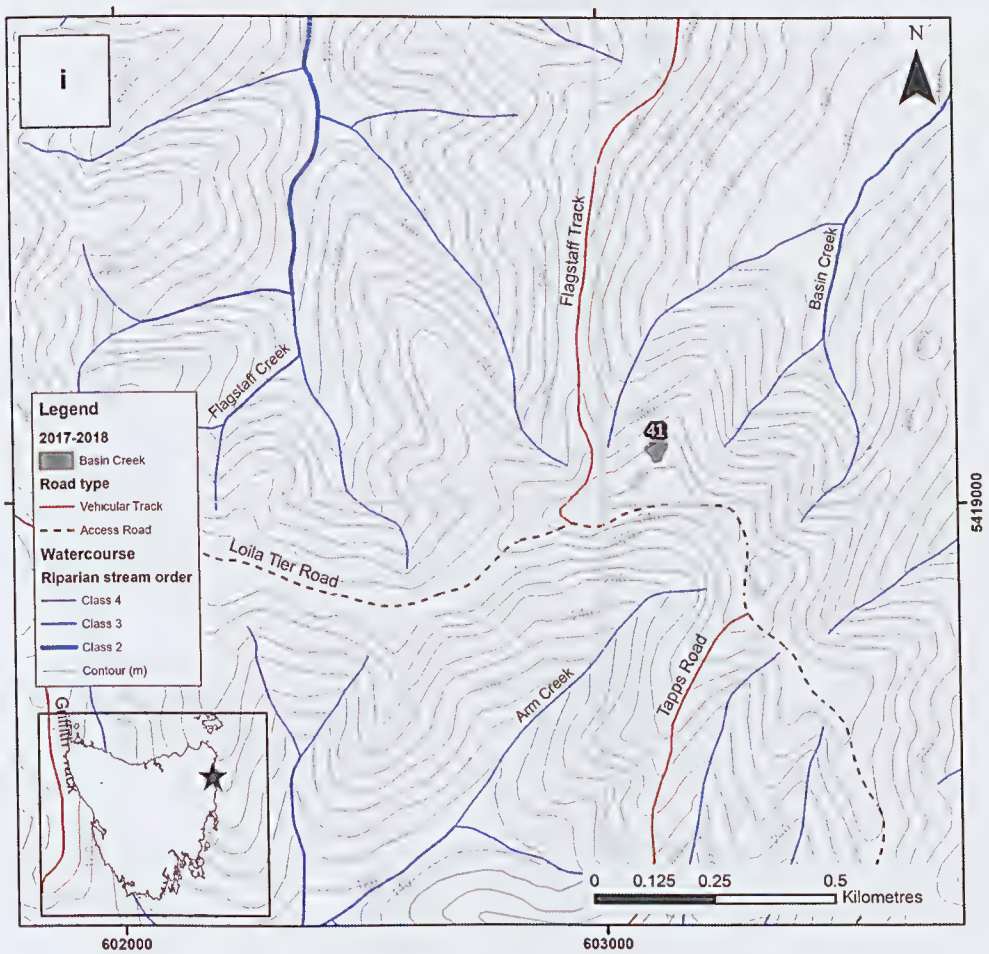
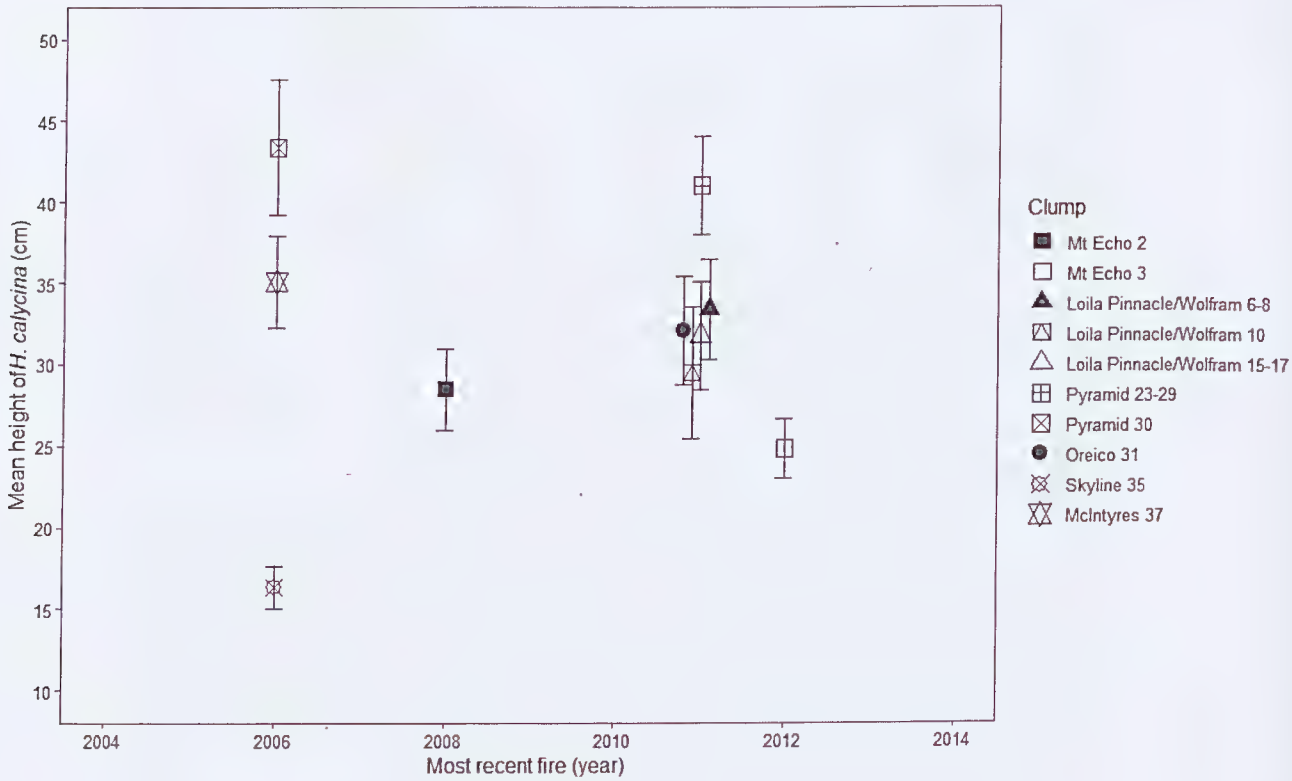




APPENDIX 3

Mean height of *H. calycina* (cm) (± 95% CI), from a random subset of clumps during the 2017/2018 survey, plotted against the most recent fire event (year). Clumps were selected based on 1995 survey clump numbers; labels are the 2017/2018 clump number. See Appendix 4 for details.



APPENDIX 4

Environmental and historical information for clumps of *Hibbertia calycina* in northeastern Tasmania.

RIDGELINE							
Tenure: 1995 and 2018	Clump no		Clump location	Landform	Fire events (month/year)	Aspect	Elevation (m)
	1995	2017/2018	2017/2018				
Mt Echo 1995: State Forest (production). 2018: Future Potential Production Forest	16,17,18	1	Mt Echo ridgeline road and northeast above Nephele Creek	ridge and mid-slope	1985–87 (frb), 10/1994 (wild), 10/2008 (frb), 10/2012 (frb)	E, NE, N, NW	130–200
	15	2	Mt Echo, northeast catchment of Constable Creek	ridge and mid-slope	11/2003 (unk), 10/2008 (frb)	N, NE	100–190
	19	3	Mt Echo, northwest ridge	ridge and mid-slope	10/2008 (frb), 10/2012 (frb)	NW	220–280
	19	4	Mt Echo, east of northwest ridge	ridge and mid-slope	10/2008 (frb)	NE	200–260
Loila Pinnacle/ Wolfram 1995: State Forest (production). 2018: Future Potential Production Forest	23	5	Loila Pinnacle	ridge	1987–88 (unk), 10/2011 (frb)	W, NW	280–350
	22	6	Loila Pinnacle	ridge	1987–88 (unk), 10/2011 (frb)	W, NW	310–370
	22	7, 8	Loila Pinnacle	ridge	1987–88 (unk), 10/2011 (frb)	N	370
	24	9	Immediately west of Loila Track (headwaters of Fitzgerald Creek)	hilltop	10/2011 (frb)	N	340–350
	26	10	Immediately west of Loila Track (headwaters of Fitzgerald Creek)	hilltop	10/2011 (frb)	W, NW	320–350
	25	11	Ridge west of Loila Track (catchment of Fitzgerald Creek)	hilltop	10/2011 (frb)	NW, W	270–320
	25	12	Ridge west of Loila Track (catchment of Fitzgerald Creek)	hilltop	10/2011 (frb)	N	190–300
	21	13	Northeast of junction of Loila Track and Wolfram Creek Track	ridge and mid-slope	10/2011 (frb)	W	250–260
	20	14	North of junction of Loila Track and Wolfram Creek Track	ridge and mid-slope	10/2011 (frb)	W	240–250
	27	15	north of Wolfram Creek Track, catchment of Fitzgerald Creek	ridge and mid-upper slope	1987–88 (unk), 10/2011 (frb)	N	120–150
	27	16	north of Wolfram Creek Track, catchment of Fitzgerald Creek	ridge and mid-upper slope	1987–88 (unk), 10/2011 (frb)	W	130–170
	27	17	north of Wolfram Creek Track, catchment of Fitzgerald Creek	ridge and mid-upper slope	1987–88 (unk), 10/2011 (frb)	W	160–170

APPENDIX 4 — cont.

Tenure: 1995 and 2018	Clump no		Clump location	Landform	Fire events (month/year)	Aspect	Elevation (m)
	1995	2017/2018	2017/2018				
Pyramid 1995: State Forest (production). 2018: Future Potential Production Forest	NA	18	southwest of Pyramid Track, catchment of Kelly Creek	hilltop/ sides of slope	1984–85 (frb), 10/2011 (frb)	W	140–170
	30	19	Pyramid Hill (continuation of ridge to northwest of main hill)	hilltop/ sides of slope	10/2011 (frb)	NW	180
	30	20	Pyramid Hill (continuation of ridge to northwest of main hill)	hilltop/ sides of slope	10/2011 (frb)	NW	190
	30	21	Pyramid Hill (continuation of ridge to northwest of main hill)	hilltop/ sides of slope	10/2011 (frb)	W	170–190
	29	22	Pyramid Hill (continuation of ridge to northwest of main hill)	hilltop/ sides of slope	10/2011 (frb)	NW	170–190
	28	23	Pyramid Hill	hilltop/ sides of slope	10/2011 (frb)	W	200–220
	28	24	Pyramid Hill	hilltop/ sides of slope	10/2011 (frb)	N	210
	28	25	Pyramid Hill	hilltop/ sides of slope	10/2011 (frb)	W	210
	32	26, 27	Pyramid Track, east of Pyramid Hill, just west of junction with Eastern Creek Road	ridge	10/2011 (frb)	N	140
	32	28, 29	Pyramid Track, east of Pyramid Hill, just west of junction with Eastern Creek Road	ridge	10/2011 (frb)	N	130
	31	30	Trout Road, northwest of Pitts Hill	ridge	1983 (unk), 08/2006 (frb; northeast side of road only)	NW, SW	120–210
Oreico 1995: State Forest (production). 2018: Future Potential Production Forest	35	31	northwest of Orieco Hill, southwest of Orieco Road, catchment of Eastern Creek	ridge	1984–85 (unk), 10/2011 (frb) (extinct northeast population [No 36 in 1995] was last burnt in 10/2012 (frb))	NW, SW	180–240
	36	extinct	Orieco Hill,	mid-upper slope		NE	110–130
	34	32	Orieco Hill, Oreico Hill top, Oreico Hill south east	ridge	10/2011 (frb)	W, SW	100–230
	33	33	Orieco Hill, Oreico Hill top, Oreico Hill south east	ridge	10/2011 (frb)	W, SW	160–210
	33	34	Orieco Hill, Oreico Hill top, Oreico Hill south east	ridge	10/2011 (frb)	W, S	190-200

APPENDIX 4 — cont.

Tenure: 1995 and 2018	Clump no		Clump location	Landform	Fire events (month/year)	Aspect	Elevation (m)
	1995	2017/2018	2017/2018				
Skyline 1995: Scamander Forest Reserve (transferred to Parks and Wildlife Service from Forestry Tasmania). 2018: Scamander Regional Reserve	37	35	Skyline Tier (near southern end and far southern end)	ridge	10/1993 (cool burn), 12/2006 (esc)	W, NW	170–180
	38	36	Skyline Tier (near southern end and far southern end)	ridge	10/1993 (cool burn), 12/2006 (esc)	W, NW	160–170
McIntyres (East) 1995: State Forest (production) 2018: Ridgeline is the boundary between Future Potential Production Forest (east of ridge so the smaller part of the sub-population) and the German Town Regional Reserve (west of the ridge so the greater part of the population)	39, 40, 41	37	McIntyres Ridge (East)	ridge and steep sides	12/2006 (esc)	W, NW	150–200
McIntyres (West) 1995: German Town Forest Reserve (transferred to Parks and Wildlife Service from Forestry Tasmania) 2018: German Town Regional Reserve	42, 43, 44	38	McIntyres Ridge (West)	ridge and steep sides	1976–77 (unk; dated from Banksia regrowth), 12/2006 (esc)	NW, N	160–290
Bolpeys 1995: State Forest (production) 2018: Permanent Timber Production Zone land	45, 46, 47	39	between Bolpeys Ridge and Catos Road (catchment of Wattle Creek)	ridge	12/2006 (esc)	W, NW	140–180
Flagstaff 1995: State Forest (production) 2018: Future Potential Production Forest	–	40	between Flagstaff Track and Boggy Creek c. 500 m ENE Flagstaff Lookout	mid-upper slope	2003/2004, 2017 (acc)	NE	140–200
Basin Creek 1995: State Forest (production) 2018: Future Potential Production Forest	–	41	north of Loila Tier Road above Basin Creek	ridge	05/2012 (frb)	N, NE	350–360

Clump numbers for 2017/18 and 1995 surveys are shown (wild: wildfire; esc: escaped burn; frb: fuel reduction burn; acc: accidentally lit; unk: unknown ignition).

APPENDIX 5

Hibbertia calycina height and fire

The assumption of homogeneity of variances for mean plant height per sub-population using 2017/2018 data only was examined using Levenes test and the difference between the mean heights of plants for each of ten clumps was tested using Welch's One-way Analysis of Variance (ANOVA). Rather than minimum and maximum, we used 95% confidence intervals to remove the influence of outliers (Walshe *et al.* 2007) except where otherwise indicated and standard error is used. Analyses were performed using R (package agricolae version 1.3-0, de Mendiburu 2019; package userfriendlyscience version 0.7.2, Peters (2018); R Core Team (2019)).

Mean plant height (± 95% confidence interval) recorded from a random subset of clumps during the 2017/2018 survey. See table 1 for clump data. One-way ANOVA was used to compare mean plant height and Tukey's test used to denote different means (denoted by letters A-G). All plants: F = 28.27 (df = 9), p <0.0001; F (Welch's ANOVA) = 52.04 (df = 9), p <0.0001.

Variable	Skyline 35	Mt Echo2	Mt Echo3	Loila Pinnacle/ Wolfram 6–8	Loila Pinnacle/ Wolfram 10	Loila Pinnacle/ Wolfram 15–17	Pyramid 23–29	Pyramid 30	Oreico 31	Skyline 35	McIntyres 37
Number of individuals	186	299	252	160	75	137	148	103	126	186	182
Mean height (cm) ± se	16.32F ± 2.85	28.46DE ± 2.50	24.83E ± 1.79	33.39CD ± 3.07	29.51CDE ± 4.04	31.77CD ± 3.34	41.02AB ± 3.02	43.37A ± 4.19	32.10CD ± 3.34	16.32F ± 2.85	35.08BC ± 2.85
Minimum height (cm)	1	2	2	2	2	1	5	4	2	1	4
Maximum height (cm)	54	120	70	82	83	81	99	133	76	54	134

There was a difference in clump mean plant height (F = 28.27, df = 9, p <0.0001). Pairwise comparisons found the mean plant height from Skyline35 was significantly different from all other clumps where height was recorded. Pyramid30 recorded the greatest mean plant height (mean = 43.37 ± 2.11 cm), similar only to nearby Pyramid 23–29 clumps). Time since the most recent fire appears to not influence the mean height of *H. calycina* plants (appendix 3). Pyramid30 and McIntyres37 ridgeline clumps recorded the high mean height of plants and longest time since fire. A clump from Skyline recorded the same time since fire and lowest mean height of plants.

References

de Mendiburu, F. 2019: agricolae: Statistical Procedures for Agricultural Research. R package version 1.3-0. https://CRAN.R-project.org/package=agricolae.

Peters, G. 2018: userfriendlyscience: Quantitative analysis made accessible_. doi: 10.17605/osf.io/txequ (https://doi.org/10.17605/osf.io/txequ), R package version 0.7.2, (https://userfriendlyscience.com).

R Core Team 2019: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. www.R-project.org/.

Walshe, T., Wintle, B., Fidler, F. & Burgman, M. 2007: Use of confidence intervals to demonstrate performance against forest management standards. *Forest Ecology & Management* **247**: 237–245.

OVERVIEW OF TASMANIA'S OFFSHORE ISLANDS AND THEIR ROLE IN NATURE CONSERVATION

by Sally L. Bryant and Stephen Harris

(with one text-figure, two tables, eight plates and two appendices)

Bryant, S.L. & Harris, S. 2020 (9:xii): Overview of Tasmania's offshore islands and their role in nature conservation. *Papers and Proceedings of the Royal Society of Tasmania* 154: 83–106. ISSN: 0080–4703. Tasmanian Land Conservancy, PO Box 2112, Lower Sandy Bay, Tasmania 7005, Australia (SLB*); Department of Archaeology and Natural History, College of Asia and the Pacific, Australian National University, Canberra, ACT 2601 (SH). *Author for correspondence: Email: sally.bryant181@outlook.com

Since the 1970s, knowledge of Tasmania's offshore islands has expanded greatly due to an increase in systematic and regional surveys, the continuation of several long-term monitoring programs and the improved delivery of pest management and translocation programs. However, many islands remain data-poor especially for invertebrate fauna, and non-vascular flora, and information sources are dispersed across numerous platforms. While more than 90% of Tasmania's offshore islands are statutory reserves, many are impacted by a range of disturbances, particularly invasive species with no decision-making framework in place to prioritise their management. This paper synthesises the significant contribution offshore islands make to Tasmania's land-based natural assets and identifies gaps and deficiencies hampering their protection. A continuing focus on detailed gap-filling surveys aided by partnership restoration programs and collaborative national forums must be strengthened if we are to capitalise on the conservation benefits islands provide in the face of rapidly changing environmental conditions and pressure for future use.

Key Words: Tasmanian islands, island conservation, island endemics, invasive species.

INTRODUCTION

Tasmania as a place is defined by islands: physically, culturally and ecologically. The enduring connection of Tasmania's Aboriginal people to offshore islands remains integral to their culture, and physical evidence of their occupation is found in cave sites, middens and artefacts, little of which has been documented. Many islands were named by the French during early scientific expeditions and are the type locations for plant and animal specimens sent back to the museums of Europe (examples in Bryant 2014, Harris 2014). Biologically, Tasmania's offshore islands contain sites of unique habitats, and in a context of uncertain environmental change, have become threatened species arks and refugia for species that are declining elsewhere (Moro *et al.* 2018). Islands through their limited size and isolation are the windows to evolution and are recognised globally for the role they play in conserving nature (Secretariat of the Convention of Biodiversity 2014). The interconnection between land and water is fundamental to island ecologies; for example, the nutrient-rich run-off from seabird and seal islands is an important driver for surrounding marine ecosystems and even phenomena such as 'Ashmole's halo' can regulate the population dynamics of seabird colonies through food depletion cycles (Gaston *et al.* 2007). The terrestrial biodiversity on islands is also supported by factors such as windthrown drifts of algal wrack and from products of nesting seabirds (Polis & Hurd 1996), which can often be important for islands with low primary productivity (Harris & McKenny 1999). However, while we recognise the intrinsic link between island landmass and sea, an analysis of marine systems is beyond the scope of this paper. Instead, we provide a land-based perspective and draw on selected historical and contemporary information to highlight the importance of Tasmania's offshore islands to nature conservation and recommend measures needed if their values are to survive in the future.

Since the 1970s our knowledge of Tasmania's offshore islands has expanded greatly. This has been due to the island field surveys attributable to biologists in the founding years of the National Parks and Wildlife Service, new sources of funding, more recent surveys and better access to island information. Two key works, one by Brothers *et al.* (2001) providing information on 280 islands and the second by Harris *et al.* (2001) on the flora of 100 islands of the outer Furneaux Group resulted from extensive fieldwork from the 1980s. Systematic surveys of heathlands, saltmarshes, eucalypt forests and wetlands included investigation of these biomes on the larger offshore islands (for example, Kirkpatrick & Harwood 1983). Knowledge of islands has continued to be supplemented through work under the Hamish Saunders Memorial Program (24 islands surveyed) and islands surveyed in anticipation of oil spill response (13 islands) (reports available DPIPWE Nature Conservation Report Series) and land management updates by the Tasmanian Aboriginal Centre (http://tacinc.com.au/programs/land-management/).

To compile this overview, we used information from the sources mentioned and a range of institutional databases, geospatial systems, web inventories, the scientific literature and the authors' professional experience. Tasmania's reserve management plans contain topographical maps, title boundaries, lists of species, history of disturbances and management regulations (http://www.parks.tas.gov.au), with many older plans also summarising widely scattered reports such as those of early field naturalists' visits. Tasmania's State of the Environment Reports were used as sequenced documents for changes in coastal and marine habitats but

these have not been updated for some time and not all are publicly available (RPDC 2006, TPC 2009).

Useful public databases include the systematic inventory of Tasmania's islands on the 'Islandshare' web portal (www.islandshare.net/), developed in 2012 by the Wildcare Friends of the Bass Strait Islands, Tasmanian Conservation Trust and Birdlife Tasmania and the Tasmanian Government's Natural Values Atlas (www.naturalvaluesatlas.tas.gov.au) which includes the Tasmanian Geoconservation Database, although this information is not island-specific.

INVENTORY AND TENURE

Mainland Tasmania has 5890 islands, islets, rock stacks and reefs located in the sea situated above the mean highwater mark (TASMAP 2006), not all of which are named. Of these, over 330 islands are greater than one hectare in size, 65 are greater than 20 hectares in size and Flinders Island (1340.4 km^2) and King Island (1093.9 km^2) are Australia's sixth and seventh largest islands. Tasmania's offshore islands are scattered around its entire coast, many occur in groups or clusters with the highest densities found in the Bass Strait region especially the Furneaux area (fig. 1). On Tasmania's northern border, Rodondo Island is less than 10 km from the Victorian coast with the border running through Boundary Islet in the Hogan Group. To the south of Tasmania, Pedra Branca and Eddystone Rock lie 27 km from South East Cape and are the southernmost exposed land on Australia's continental shelf. A further 1,500 km to the south is subantarctic Macquarie Island which became part of Tasmania's territorial jurisdiction during the Van Diemen's Land proclamation in 1825.

Few of Tasmania's offshore islands are permanently settled. The larger King, Flinders, truwana-Cape Barren and Bruny islands have established population centres and some others, for example, Maria, Macquarie, Deal, Maatsuyker, Robbins, Three Hummock, Swan and lungtalanana-Clarke islands have staffed field stations, private houses or visitor accommodation. Many islands, however, retain a range of infrastructure such as lighthouses (pl. 1), airstrips, fences, tracks, homesteads and huts, reflecting current or past use and are visited for a variety of purposes.

From the 1970s onwards Tasmania's offshore islands were systematically reviewed for statutory protection. Maria, Schouten, Tasman, South Bruny and the Kent Group of

FIGURE 1 — Flinders Island showing density of surrounding islands.

PLATE 1 — Maatsuyker Island showing lighthouse station and the Needle Rocks offshore.

islands, were all incorporated into the boundary of existing national parks whereas other islands transitioned in status over time from unallocated Crown land or private lease, to Game Reserve, Conservation Area or Nature Reserve depending on their values. Macquarie Island, including Judge and Clerk and Bishop and Clerk islets, was proclaimed a Wildlife Sanctuary in 1933, a Conservation Area in 1971, State Reserve in 1972, Nature Reserve in 1978 and in 1997 was inscribed on the World Heritage List (PWS 2006) with its boundaries extended several times since to incorporate marine reserves. The Tasmanian Wilderness World Heritage Area incorporates numerous islands around the southwest coast, the larger being the Maatsuyker Island Group, De Witt, Ile du Golfe, Louisa Island, Hen and Chicken Islands, Pedra Branca, Mewstone, Eddystone Rock, Trumpeter Islet, Muttonbird Island, Breaksea Island and the Swainson Group (DPIPWE 2016).

Of Tasmania's larger offshore islands, 229 islands (more than 90% of them) have some level of statutory protection (table 1). This includes 75 islands previously classified as non-allocated Crown land but declared Conservation Areas through the Crown Lands Assessment Classification process in 2012. In 1995, as an act of reconciliation, the Tasmanian Government transferred control of seven islands (titima-Trefoil, Babel, Badger, Big Dog, Hummocky-Mt Chappell, Steep, lungtalanana-Clarke) and most of truwana-Cape Barren Island to the Aboriginal Land Council of Tasmania. Five of these islands are registered Indigenous Protected Areas (IPAs) managed by the Tasmanian Aboriginal Centre, which also manages 'Wybalenna' on Flinders Island and a small parcel of coastal land at Great Bay, Bruny Island. 'Murrayfield Station' on Bruny Island (4,097 ha) is owned and managed by the Indigenous Land Corporation.

Over thirty Reserve Management Plans and Indigenous Healthy Country Plans contain over 112 islands within their jurisdictional boundary; however, some plans (e.g., *Small Bass Strait Island Reserves*, *Small North-East Islands* and *Small South-East Islands*) have been in draft form for nearly two decades awaiting formal adoption (https://parks.tas.gov.au/about-us/managing-our-parks-and-reserves/management-plans-reports).

TABLE 1 — Status of Tasmania's larger offshore islands.

Statutory Reserves	No.
National Park	62
Conservation Area	103
Nature Reserve	44
State Reserve	4
Game Reserve	9
Nature Rec. Area, Historic Site	2
Indigenous Protected Area	5
Total	229

Multi or Private Tenure	No.
Private Freehold	9
Multiple Land Tenure (Aboriginal, private, reserved)	12
Aboriginal Lands (Trefoil, Steep)	2
Total	23

Source: http://www.islandshare.net/; https://eatlas.org.au/node/1703.

Tasmanian Parks and Wildlife Service is the land manager for islands or parts of islands reserved under the *National Parks and Reserves Management Act 2002* and the Tasmanian Aboriginal Centre manages IPAs dedicated under the International Union for Conservation of Nature (IUCN). There is no single managing authority for unreserved islands in Tasmania; instead a range of state and local government agencies in accordance with Tasmania's Resource Management and Planning System (TPC 2009) are responsible for aspects of their management and protection.

NATURE CONSERVATION VALUES

Geo-conservation values

Macquarie Island, Tasmania's only oceanic island, gained World Heritage status for its globally significant geological formation and is the only island in the world composed entirely of oceanic crust and rocks originating from deep below the Earth's surface (Williamson 1988). Macquarie Island is the only place where this exposed rock sequence is a uniquely complete section which can be studied in detail to better understand the processes of oceanic crust formation and plate boundary dynamics above sea-level (Comfort 2014).

All of Tasmania's nearer offshore islands were formed as the sea level rose after the Last Glacial, hence their geologies are often directly related to the adjacent mainland (Jennings 1959, Dixon 1996). King Island and the Fleurieu Group formed part of the peninsula northwest from Tasmania, and the Furneaux Group (and Kent and other island groups to the north) were part of the Bassian Rise land bridge between Tasmania and Victoria in the east.

Tasmania's islands are a range of hard and soft rock features, sandy dunes, spits, tombolos and isthmuses, with some displaying a range of significant geological features and diverse landforms (Banks 1993, Dixon 1996, Seymour *et al.* 2007). Features illustrating this diversity include: the tombolo on Actaeon Island, the tessellated pavements of Reid Rocks, the caves on Erith Island and De Witt, the lagoon on Southwest Island and the flowstone comprised of seal excrement on Judgement Rock.

Eberhard (2011) observed several bizarre-shaped weathered boulders on the coast of Inner Sister Island and identified the fabric of the granitic rock (mineral segregations and/or xenoliths) and presumed Pleistocene colluvial fans as features worthy of listing on the Tasmanian Geoconservation Database. On Hunter Island he identified the Cave Bay raised sea cave, Hunter Island cobble berms, and the Hunter Passage perched lagoons as being distinctive in the broader western Bass Strait region and also worthy of inclusion (Eberhard 2017).

On King Island, the Cambrian rocks along the City of Melbourne Bay foreshore contain globally significant lava pillows demonstrating seafloor volcanism, with other islands in northwest Tasmania, e.g., Robbins Island, displaying outstanding examples of beach ridge sequences marking at least two major phases of Quaternary activity. Maria Island's fossil cliffs, gulches, sea caves, raised shore platforms, blow hole and a razor-backed saddle-ridge are recognised as a globally unique set of features. The spectacular parallel dune systems enclosing brackish lagoons along the east coast of the Furneaux Islands, and the saline lagoon systems of truwuna-Cape Barren Island and lungtalanana-Clarke Island, are also of high geo-conservation significance (Dixon 1996).

Other islands of geo-significance are Black Pyramid for its Tertiary basaltic volcanic features, the sea caves and seal-related flowstone of Ile des Phoques, the geology of Pedra Branca and Eddystone Rock, and Tasman Island for its well-exposed columnar dolerite (pl. 2).

Fauna values

Over one third of Tasmania's land-based threatened fauna species occur on offshore islands (63 of 181 species, 35 %, appendix 1) demonstrating the significant role islands play in fauna conservation. Some islands are critical breeding sites or provide seasonal foraging habitat and some faunal groups, particularly island endemics or invertebrates, and found in only one island location. Even though the invertebrate values on Tasmania's offshore islands are becoming better known, this faunal group remains significantly under-surveyed. The coastal mollusc fauna on King Island contains at least 408 species with 78 being recorded for the first time by Grove and de Little (2014). Hamish Saunders Memorial Island surveys and Oil Spill Response surveys have targeted the

PLATE 2 — Dolerite structural columns on Tasman Island.

PLATE 3 — Rare Tasman Island Cricket *Tasmanoplectron isolatum*.

collection of invertebrates during their expeditions often focusing on threatened species or specific groups such as butterflies, grasshoppers, freshwater crayfish or molluscs, and invariably these surveys have resulted in new species finds and range expansions. For example, the invertebrate surveys conducted on Tasman Island identified a new snail species, Planilaoma? sp. nov. "Tasman Island", a previously undescribed snail species, Pedicamista sp. "Southport", and the lodgement of voucher specimens of the rare Tasman Island Cricket *Tasmanoplectron isolatum* (Bryant & Shaw 2006, pl. 3). New records of the molluscan *Magilaoma penolensis* and *Scelidoropasp* "Ridges Road" were made on Rodondo Island (Carlyon *et al.* 2015) and a species of stick insect was recorded for the first time in the eastern Bass Strait on Inner Sister Island (Harris & Reid 2011). Unique assemblages of troglobitic cave invertebrates occur on Flinders Island and range extensions for other species such as the endemic Furneaux Burrowing Crayfish *Engaeus martigener* and Fringed Heath-blue Butterfly *Neolucia agricola insulana* (NCHD 2014) have been made there. The discontinuation of integrated island survey programs has meant that invertebrates are now often overlooked during short-stay visits and this gap in knowledge concurs with Mesibov's (2019) findings of a decrease in records of invertebrates lodged in museums and on databases since the turn of the century.

Islands are recognised globally as places with high levels of endemism and sites of extinction, and Tasmania's islands follow this trend. In addition to the Thylacine *Thylacinus cynocephalus* and Tasmanian Emu *Dromaius novaehollandiae diemenensis* now extinct on mainland Tasmania, three island-specific endemic vertebrate species or subspecies have been destroyed on Tasmania's islands (Macquarie Island Parakeet *Cyanoramphus erythrotis*, Macquarie Island Rail *Gallirallus philippensis macquariensis*, King Island Emu *Dromaius novaehollandiae minor*) with a probable fourth, a Macquarie Island seal species, exterminated before it was scientifically described (Terauds & Stewart 2009). Even more localised island extinctions have occurred. For example, on King Island, the King Island Emu, Forty-spotted Pardalote *Pardalotus quadragintus*, Spotted-tailed Quoll *Dasyurus maculatus*, Common Wombat *Vombatus ursinus* and Southern Elephant Seal *Mirounga leonine* are now extinct with a further 12 island species on the verge of extinction including the critically endangered King Island Scrub Tit *Acanthornis magnus greenianus* and King Island Brown Thornbill *Acanthiza pusilla subsp. archibaldi* (Donaghey 2003, TSS 2012, Webb *et al.* 2016). Other examples of regional extinctions are: Australian Sea Lions *Neophoca cinerea* no longer breed in Bass Strait after being eliminated on Christmas and New Year islands by harvesting in the nineteenth century, and an Australasian Gannet *Morus serrator* colony destroyed on Cat Island in the Furneaux Group before protective measures could be implemented (D. Pemberton, pers. comm).

The core breeding range for the Nationally Endangered Swift Parrot *Lathamus discolour* and Forty-spotted Pardalote centre on Flinders Island, Bruny Island and Maria Island and the Critically Endangered Orange-bellied Parrot *Neophema chrysogaster* depends on saltmarsh habitat on King Island and probably uses a number of northwest islands during its annual autumn migration (Bryant & Jackson 1999). On Flinders, truwuna-Cape Barren and lungtalanana-Clarke islands (pl. 4), the saltmarsh communities, heathland and remnant forests are breeding sites for threatened or naturally restricted species such as the Dwarf Galaxias *Galaxiella pusilla*, New Holland Mouse *Pseudomys novaehollandiae*, Green and Gold Bell Frog *Litoria aurea* and other genetically or regionally distinct fauna species (e.g., Bass Strait Common Wombat *Vombatus ursinus subsp. ursinus*, Chappell Island Tiger Snake *Notechis scutatus*). Islands are also microcosms for bird species like Silvereye *Zosterops* or poor-dispersers such as scrub wren *Sericornis* sp. and thornbill *Acanthiza* sp. which all over the world have evolved into specific island forms (Kirkwood & O'Connor 2010) and in Tasmania show distinct behavioural or morphological variation in the Bass Strait region (Bryant & Carlyon 2013). Pedra Branca

PLATE 4 — Northeast ridge on Mt Munro, truwuna-Cape Barren Island, looking across to Mount Strzelecki on Flinders Island.

islet (2.5 ha, pl. 5) is one of only three breeding sites for Endangered Shy Albatross *Thalassarche cauta* and critical habitat for the endemic Pedra Branca Skink *Niveoscincus palfreymani*, one of the rarest and most restricted reptiles in the world (Threatened Species Unit 2001).

The Ramsar wetlands of Lavinia (King Island), Logan Lagoon (Flinders Island) and truwuna-Cape Barren Lagoons are essential feeding sites for migratory waders during their annual East Asian migration (Woehler & Ruoppolo 2010) and the islands in the Boullanger Bay-Robbins Passage area are the stronghold for 17 species of migratory and resident waders including Hooded Plover *Thinornis rubricollis*, Pied Oystercatcher *Haematopus longirostris*, Little Tern *Sternula albifrons* and Fairy Tern *Sternula nereis* (Bryant 2002). These values are recognised internationally with 29 Important Bird Areas (IBAs) designated wholly or partly on Tasmanian islands, the highest number of island-IBAs of any Australian state (Kirkwood & O'Connor 2010).

Tasmania's islands are central to the ecology of all our land-breeding marine vertebrates including globally threatened albatrosses, giant petrel and burrowing seabird species and seal species (Bryant & Jackson 1999). Over 60 species of seabird including massive aggregations of Short-tailed Shearwater *Ardenna tenuirostris* and Little Penguin *Eudyptula minor* breed on the Bass Strait islands, including those in the Hogan Group (Brothers *et al.* 2001, Carlyon *et al.* 2011). Sub-Antarctic Macquarie Island has an estimated biomass of 3.5 million breeding seabirds, predominantly penguins with some (e.g., Royal Penguin *Eudyptes schlegeli*, Macquarie Island Shag *Leucocarbo purpurascens* and several species of burrowing petrel) breeding only there (Bryant & Shaw 2007, Terauds & Stewart 2009).

PLATE 5 — Pedra Branca Islet located ~ 27 km off South East Cape.

Flora values

The flora species on the littoral margins of the large islands and all low-lying islands are predominantly vagile and consequently tend to be widespread in occurrence. The autochthonous components of the floras on the larger islands are of special significance in some localities where the vegetation and floras are the result of climatic and fire factors peculiar to those sites. For example, Rodondo Island supports climax communities of *Eucalyptus globulus*, and *Melaleuca armillaris* as well as several plant taxa of regional biogeographic significance (Carlyon *et al.* 2015) which have evolved in the long absence of fire. Rodondo and Craggy islands also have one of the few indigenous Tasmanian occurrences of the shrub *Paraserianthes lophantha*, representing the eastern extremity of its natural distribution (Harris *et al.* 2001). Bass Strait islands are of particular biogeographical interest. The cloud forest on Mt Strzelecki on Flinders Island contains rainforest elements such as *Atherosperma moschatum* and a high proportion of the 137 species of liverworts and mosses recorded for the Strzelecki National Park (Harris *et al.* 2015). Such species assemblages assist in unravelling the palaeoenvironmental history of Bass Strait. The cloud forest on Mt Munro on truwuna-Cape Barren Island has the only Tasmanian stands of the tree *Bedfordia arborescens* within an unusual mosaic of plant communities (Harris & Lazarus 2006).

The east shelf of Maria Island has an ecologically important forest boundary, where stands of pure *Callitris rhomboidea* abut *Phyllocladus asplenifolius*-dominated rainforest, a situation attributable to an unusual combination of site factors, one of which appears to be the stripping of moisture by the rainforest from easterly sea mists. Such a sharp boundary between climax dry forest and climax cool temperate rainforest is significant in demonstrating the coincidence of forest types which may have been more common prior to the radiation of the eucalypts.

Many islands have one or more threatened plant species (appendix 2) or vegetation communities. For example, Bruny Island has approx. 39 state or nationally threatened plant species (Cochran 2003), and in 2019 a population of *Acacia acinacea* new to Tasmania was identified there (TLC 2019). In Bass Strait, *Apium insulare* and *Bulbine crassa* (pl. 6) represent taxa confined to the islands according to present knowledge, with so many other species such as *Isopogon ceratophyllus* and *Leiocarpa supina* occurring there as distribution range outliers.

Other island floras of national significance occur on Ile du Golfe, Maatsuyker Island and Flat Witch in the Tasmanian Wilderness World Heritage Area (Balmer *et al.* 2004) and the limestone flora on Prime Seal Island retains direct affinities with the Recherche Archipelago in Western Australia and the limestone coastal flora of South Australia (Harris *et al.* 2001). Deal Island in the Kent Group was visited in 1803 by the botanist Robert Brown who consequently made this the type locality for several plant taxa he collected there and first described.

Macquarie Island has a unique assemblage of vegetation communities and 48 plant species including four endemics (de Salas & Baker 2018), with one of these endemics, the critically endangered cushion-forming *Azorella macquariensis*, a dominant species of the fjaeldmark community (Selkirk *et al.* 1990).

INTRODUCTIONS AND TRANSLOCATIONS

Islands are often regarded as stocking grounds for plants and animals declining elsewhere. Historically, several islands in Tasmania have had ad hoc releases such as Koala *Phascolarctos cinereus*, Forester Kangaroo *Macropus giganteus* and Cape Barren Geese *Cereopsis novaehollandiae* to Three Hummock Island (Bryant 2008) and Tasmanian Devil *Sarcophilus harrisii* to Badger Island in 1996 (DPIPWE 2010a). By

PLATE 6 — Island Leek Lilly *Bulbine crassa*, Neds Reef, near truwana-Cape Barren Island.

far the highest number of alien introductions have been to Maria Island with over 90 exotic plant species introduced as ornamental plants or for cultivation and 19 vertebrate species actively liberated or a legacy of European settlement (PWS 1998). Fallow Deer *Dama dama* were introduced to the pastures around Frenchs Farm but eradicated in 1998. Forester Kangaroo and Cape Barren Geese were introduced as they were declining in populations elsewhere and in 1968 Australian Emu *Dromaius novaehollandiae* were introduced in a failed experiment to recreate the extinct Tasmanian Emu but were removed in the 1980s (Rounsevell 1989). Between 1969 and 1972, over 760 individuals from 13 species of mammal and bird were liberated on Maria as a potential food source for Thylacine should they ever be re-discovered and need to be relocated there (National Parks & Wildlife Service 1972). The legacy of these multiple introductions has compounded disturbance to Maria's ecosystem and imposed a burden of ongoing management to reduce several problematic species.

In 2012, Nationally Endangered Tasmanian Devils free of facial tumour disease were released on Maria Island to establish a free-ranging population under an approved translocation plan. Devils have subsequently successfully established and bred to a level where they are now being actively removed to re-populate mainland Tasmania sites (Wise *et al.* 2016). Tasmanian islands also provide opportunities for plant translocations though few have been undertaken to date. An ex-situ planting of the Critically Endangered endemic *Epacris stuartii* on Southport Island was undertaken in 2001 to prevent the species extinction should *Phytophthora cinnamoni* infect the only known wild population on nearby Southport Bluff. Recent suggestions of re-wilding some Bass Strait islands by reintroducing native extirpated predators to benefit threatened species is a novel approach which may become a recognised conservation tool of the future (Fielding *et al.* 2020).

ISLAND MONITORING PROGRAMS

It is difficult to assess the trends in the condition of Tasmania's offshore island environments as no baseline indicators are in place (Tasmanian Planning Commission 2009). However, at least 50 islands undergo repeat site visits to assess vertebrate breeding populations or monitor numbers; the most regularly visited are shown in table 2. One of the longest running wildlife monitoring programs in the world is on Fisher Island, where Short-tailed Shearwaters have been monitored annually since 1947 when first established by the ornithologist Dominic Serventy (Bradley *et al.* 2008).

TABLE 2 —Vertebrate assessments on Tasmanian islands.[1,2]

Species or group	Islands monitored
Australian fur seal breeding and haul-out sites	Maatsuyker, De Witt, Needles, Walker, Little Witch, Pedra Branca, Mewstone, Sugarloaf Rocks, Tasman, Hippolyte Rock, Albatross, Black Pyramid, Tenth, Judgement Rocks, West Moncoeur, Bass Pyramid, Wright Rocks, Reid Rocks, East Moriarty, West Moriarty Rocks; Bull Rocks, Ile des Phoques, Bruny, The Friars
Shy Albatross	Albatross, Mewstone, Pedra Branca
Albatrosses (4 species), Giant Petrel (2 species), burrowing seabirds (21 species), penguins (4 species), seals (5 species)	Macquarie
Australasian Gannett	Pedra Branca, Eddystone, Black Pyramid, Bass Pyramid, Cat
Little Penguin	Bruny, Ninth, Passage, Forsyth, King, Councillor, Georges Rocks, Diamond, Maria, Schouten, Huon, Tasman, De Witt, Maatsuyker, Louisa, Flinders
Pacific Gull	Goose, Flinders
Shorebirds (~17 resident and migratory species)	Robbins, Walker, Perkins, Kangaroo, Wallaby Islets, Montague, Maria, Flinders, Cape Barren, King, Bruny
Forty-spotted Pardalote, Swift Parrot	Maria, Flinders, Bruny including Partridge
Orange-bellied Parrot	King, Robbins, Walker, Perkins, Port Davey islands
Eagles (2 species)	Most regularly Maria, Bruny, Flinders
Short-tailed Shearwater, Cape Barren Goose, Brown Quail	Maatsuyker, Fisher, Big Green, East Kangaroo, Little Green, Great Dog, Little Dog, Chappell, Bruny, Tasman, Flinders, Vansittart, Tin Kettle, Woody, East Kangaroo, Goose, Isabella, Inner Sister, Badger
Pedra Branca Skink	Pedra Branca
Common Pheasant	Hunter group, Furneaux group, King
Macropods, Brush-tailed Possum	Maria, Flinders, King

[1] Visits may be irregular or repeat visits for breeding or population assessments, or determining harvesting quotas, etc.

[2] Referenced from multiple sources including back issues of *Game Tracks* (https://dpipwe.tas.gov.au/Documents/Game-tracks.pdf), Driessen & Hocking (2008).

Short-tailed Shearwater, Cape Barren Geese and Brown Quail *Coturnix ypsilophora* are monitored on several islands in the Furneaux Group to determine harvesting quotas (Wildlife Management Branch 2010) and over 20 islands and rock stacks are surveyed regularly for Australian Fur Seal *Arctocephalus pusillus* activity (Bryant & Jackson 1999, Kirkwood *et al.* 2010). Shorebirds are surveyed seasonally on multiple islands in Boullanger Bay area, with over 70 islands having been surveyed repeatedly for these species during the past 30 years (Bryant 2002, Woehler & Ruoppolo 2010). Critical research on Shy Albatross has been undertaken on Albatross Island, Mewstone and Pedra Branca for over 20 years as part of this species recovery efforts, and monitoring programs on Macquarie Island have been critical to determine population numbers pre- and post-pest eradication programs (Springer 2018). Another Macquarie Island research program monitoring the impact of European Rabbit *Oryctolagus cuniculus* browsing on sensitive vegetation has continued since 1981 (Whinam & Shaw 2018).

THREATS

Invasive species

Invasive species are an insidious threat that impact most of Tasmania's offshore islands and often go unnoticed and unmanaged. While no current comprehensive information exists on the number of Tasmanian islands impacted by invasive species, at least 70 have been recorded with introduced mammal species (Brothers *et al.* 2001, Terauds 2005, Pfennigwerth 2008, TPC 2009). The most commonly recorded are European Rabbit *Oryctolagus cuniculus*, feral Cat *Felis catus*, Black Rat *Rattus rattus*, House Mouse *Mus musculus* and a variety of domestic stock. Feral Pigs *Sus scrofa* are widespread on parts of Flinders Island since their introduction in the early 1880s (Statham & Middleton 1987) and recent Fallow Deer *Dama dama* have yet to be removed from the wild on Bruny Island and King Island. Many introduced bird species occur on islands often liberated for hunting or pleasure such as Ring-necked (Common) Pheasant *Phasianus colchicus*, Turkey *Meleagris gallopavo* and Indian Peafowl *Pavo cristatus* on Flinders Island and King Island.

Weeds are widespread on even more offshore islands, many being either cosmopolitan or ruderal species or possibly benign in their ecological impacts. Weeds that pose problems include, for example: African Boxthorn *Lycium ferocissimum*, Gorse *Ulex europaeus*, Canary Broom *Genista monspessulana*, Spanish Heath *Erica lusitanica*, Shining Coprosma *Coprosma repens*, Blackberry *Rubus fruticosus* and Sea Spurge *Euphorbia paralias*. Marram Grass *Ammophila arenaria* was introduced to Tasmania to stabilise sand dunes and is now widespread and well-established on the sandy coasts of most near onshore islands. Macquarie Island has seven alien plant species, two of which *Anthoxanthum odoratum* and *Rumex crispus* have already been removed (de Salas & Baker 2018).

The occurrence of the water mould *Phytophthora cinnamomi* is a significant cause of degradation in heathland communities on larger islands such as Schouten Island, Three Hummock Island, Flinders Island, truwuna-Cape Barren Island and lungtalanana-Clarke Island where it infests swathes of heathland. The result is the selective mortality of plants in the susceptible families, especially Proteaceae, Myrtaceae, Ericaceae and Fabaceae.

Until recently, vertebrate control programs on islands have been largely ad-hoc with mixed success. However, over the past decade Tasmania has significantly improved its eradication methodologies with several now cited as exemplars of success. Pest management on Macquarie Island had systematically eradicated Weka *Gallirallus australis* by 1988, feral Cats by 2002, and finally Rabbits, Black Rat and House Mouse by 2014 in a multipronged multi-species approach (Springer 2018, pl. 7). Feral Cats have been eradicated from Tasman Island and Wedge Island (Robinson *et al.* 2015, Robinson & Gadd 2020), House Mouse from Fisher Island (S. Robinson, pers. com.) and Black Rat from Big Green Island (Robinson & Dick 2020) with planning underway on other islands. The Bruny Island Cat Management program commenced in mid-2016 and has already significantly reduced cat numbers aiming to meet the Commonwealth's target of being one of Australia's Five Cat Free Islands (Allan 2019). Several feasibility plans have been prepared for the removal of feral Pig *Sus scrofa* from Flinders Island, but none have yet to secure funding. The improved success of government-led eradication efforts has been largely due to a combination of

PLATE 7 — European Rabbit denuding the slopes of Macquarie Island prior to eradication.

PLATE 8 — Taillefer Rocks off Schouten Island, Freycinet National Park.

better planning, improved technology, aid from volunteer labour and philanthropic financial support (Springer 2018, Robinson & Dick 2020).

Uncontrolled access

Inappropriate or uncontrolled access to islands can cause disturbance to sensitive breeding species, and increase the risk or spread of invasive species, disease and fire. Several Tasmanian islands restrict public access unless authorised by permit (Macquarie Island, Judgement Rocks, North East Isle, South West Isle, Vissher Island, Ile de Phoques, Albatross Island, Rodondo Island and others) and partial restrictions apply to a number of islands within Freycinet National Park (The Nuggets, Refuge Island, Promise Rock, Lemon Rock, Half Lemon Rock, Eastern Rock and Taillefer Rocks (pl. 8)).

A government protocol is in place which identifies 12 steps to preventing pests, weeds and diseases spreading to Tasmania's islands (http://www.islandshare.net/Documents/Island_Biosecurity_Guide.pdf), with additional biosecurity measures recommended for islands in Tasmania's Southwest Wilderness Area (Mallick & Driessen 2009). Minimal impact guidelines have been prepared for sea kayakers to ensure that sensitive areas are not disturbed or compromised during recreational visits which for some even remote islands have become a constant summer destination (D. Pemberton, pers. com.). Rigorous biosecurity procedures are in place for Macquarie Island and these are included as part of the guidelines for tourist operations to the island (PWS 2006, http://www.parks.tas.gov.au/).

Climate change

Australia's most recent species extinction resulting from the loss of habitat by sea level rise (Woinarski et al. 2018) was the endemic Bramble Cay *Melomys Melomys rubicola*, from the northern Great Barrier Reef. More than 1,440 km of Tasmania's coast is subject to flooding, and over 975 km of shoreline at risk of erosion, sand dune mobility, rock falls and slumping as a result of sea level rise and more frequent storm surges (Sharples 2006, DPIPWE 2010b). A rise in mean sea level due to global warming of between 5 cm and 14 cm for Tasmania is projected to occur by 2030 meaning 1-in-100-year storm tide events could occur as frequently as once every 50 years, and are therefore likely to impact all low-lying Tasmanian islands. Southeastern Tasmania is predicted to experience the greatest increase in sea surface temperature and in Mercury Passage the rise of 1.6°C recorded in the past 50 years, is already three times the average rate of global warming (ACE CRC 2010, Parsons 2011). Ocean acidification and reduced calcification is anticipated to cause increased erosion of coral reefs like those off the islands in the Kent Group, having potential consequences for the marine food chain (TPC 2009). Australia-wide nearly 20% of migratory bird species are likely to be affected through the loss of habitat due to sea level rise and coastal development (Mallon 2007). Loss of frontline beach foredune, shrubland communities and tussock grassland will reduce breeding habitat for marine seabirds, most of which have high site fidelity. Sea level has fluctuated during the Holocene and there is evidence of fossil shorelines many metres above the current high-water mark. The response of the terrestrial biota to such sea level changes is poorly understood, although the ameliorative effects of higher sea levels in creating new habitats has been investigated by Prahalad and colleagues on coastal saltmarshes. They use predictive models to anticipate where new habitat may be created under different sea level change scenarios (e.g., Prahalad *et al.* 2012, Prahalad & Pearson 2013). Seminal research on the Macquarie Island Cushion Plant identified the cause of its decline was due to a climatic shift, exposing this unique cold, wet adapted species to prolonged periods of drying (Whinam & Shaw 2018). The long-term monitoring of island species in remote environs is often pivotal for identifying the impact of insidious threats and recommending recovery actions that could benefit groups of co-located species (e.g., response of burrow nesting petrels to climate change in Brothers & Bone 2008).

ISLAND PARTNERSHIPS

Volunteers and philanthropic partnerships remain instrumental in helping deliver a range of conservation initiatives on Tasmania's islands and are pivotal for ongoing success (Bryant & Copley 2018). Groups such as the Bruny Island Environmental Network are community-based collectives that assess policy, development applications and all manner of local issues to ensure transparency and protection of island values. Since the 1970s Birdlife Tasmania volunteers have collected bird data on species distribution, sensitive bird breeding islands (www.birdlife.org.au/locations/birdlife-tasmania) and assisted in island monitoring and eradication efforts. In 2020 Wildcare Tasmania (www.wildcaretas.org.au/) had 11 registered island-specific Wildcare groups contributing to weed removal, track or heritage restoration or caretaker positions on islands. Some, for example, the Friends of Bass Strait Islands manage weed removal on ten outer Furneaux Islands, and the Friends of Maatsuyker Island undertake lighthouse preservation, caretaker duties, weed removal and seabird monitoring, often at their own expense (Bryant & Copley 2018). The Cradle Coast Authority is aiming to protect shorebird species on Three Hummock Island by removing feral Cats and controlling Sea Spurge and other weeds in the Robbins Passage area.

The Tasmanian Aboriginal community including the Tasmanian Aboriginal Centre and the people on truwuna-Cape Barren Island, Flinders Island and Bruny Island have formed strong partnerships with a range of government and private bodies to undertake research and collaborate on land management projects on their islands, including with Australian National University researchers, allowing the investigation of palaeoenvironments reconstructed from sediment and pollen cores (McWethy *et al.* 2017).

Since 1989 the Princess Melikoff Trust has financially supported government marine mammal conservation by funding surveys of seal breeding and haul-out sites on numerous islands around Tasmania, and from 2003 to 2017 a partnership with the Hamish Saunders Memorial Island Survey Program facilitated multi-disciplinary expeditions to 24 offshore islands and the publication of results. While several commercial businesses (e.g., Maria Island Walk (www.mariaislandwalk.com.au)) support local island initiatives, the most influential island partnership to date has been with Pennicott Wilderness Journeys, who make sizeable donations from the Pennicott Foundation which have been pivotal in the success of so many island management programs (https://www.pennicottfoundation.org.au/projects/).

Collaborating in international symposia like the Small Island Developing States (www.first.org/events/symposium/nadi2019/) and the National Island Arks Symposia (http://islandarks.com.au/) are instrumental for the sharing of knowledge across multi-disciplines dealing with island management including the role of local communities and indigenous practice. Participation in collaborative forums such as these is essential for island managers to discuss commonly shared problems as islands become increasingly more attractive for developments and expanding populations at the cost of their natural values.

CONCLUSIONS

Tasmania's offshore islands contain globally unique natural values and play a significant role in nature conservation, but their ongoing management is necessary to prevent degradation and local species extinction. A national review by Ecosure (2009) identified 15 Tasmanian islands among Australia's top 100 most conservation important islands greater than 200 ha in size. While those identified are significant, size is not a valid criterion to determine conservation value as most, even small, islands can contain inherently unique assemblages. Management of islands requires a multi-disciplinary approach supported by comprehensive evidence and a decision support system (Lohr *et al.* 2018) that can simplify the myriad of possible actions involved in protecting island species. One such system designed by Helmstedt *et al.* (2016) for island invasive species eradication factored in a range of attributes including likelihood of success and cost-effectiveness, and demonstrated that for a fixed budget, a higher conservation benefit could be achieved across multiple islands. Assigning a set of baseline indices for island condition are also essential if we are to track the ecological health of islands in response to management programs or pressures from future use or climate change.

Due to competing demands and costs associated with their access and management, islands seldom receive the timely attention they deserve, leaving them exposed to existing and emerging threats including inappropriate development. Designating islands that contain important nature conservation values as 'Matters of National Environmental Significance' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) has been proposed by Woinarski *et al.* (2018). This mechanism could be strengthened further by the listing of 'important island populations' as threatened communities or threatened ecosystems under Tasmania's *Nature Conservation Act 2001.* If important islands were designated as a 'threatened ecological community' it might focus attention and justify the direction of additional resources towards their management.

With improving knowledge, technology and increased volunteer-philanthropic support, invasive species are being reduced with greater efficiency providing island systems time to recover. However, these efforts need to be supported and expanded if we are to retain our unique island ecologies in the future.

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REFERENCES

ACE CRC 2010: *Climate Futures for Tasmania: extreme events: the summary.* Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania: 12 pp.

Allan, K. 2019: Bruny Island cat management project. Project update Feb 2019–July 2019. Kingborough Council: 14 pp (www.kingborough.tas.gov.au/wp-content/uploads/2020/07/Bruny-cat-management-update_Oct-2019.pdf).

Balmer, J., Whinam, J., Kelman, J., Kirkpatrick, J.B. & Lazarus, E. 2004: A review of the floristic values of the Tasmanian Wilderness World Heritage Area. Nature Conservation Report 2004/3. DPIWE, Hobart, Australia: 133 pp.

Banks, M.R. 1993: Reconnaissance geology and geomorphology of the major islands south of Tasmania. Report to the Department of Parks, Wildlife and Heritage, Tasmania: 40 pp.

Bradley, J., Skira, I. & Wooller, R. 2008: A long-term study of Short-tailed Shearwaters *Puffinus tenuirostris* on Fisher Island, Australia. *Ibis* **133**: 55–61.

Brothers, N. & Bone, C. 2008: The response of burrow-nesting petrels and other vulnerable bird species to vertebrate pest management and climate change on sub-Antarctic Macquarie Island. *Papers and Proceedings of the Royal Society of Tasmania* **42(1)**: 123–148.

Brothers, N., Pemberton, D., Pryor, H. & Halley, V. 2001: *Tasmania's Offshore Islands: Seabirds and Other Natural Features.* Tasmanian Museum and Art Gallery, Hobart: 643 pp.

Bryant, S.L. 2002: *Conservation assessment of beach nesting and migratory shorebirds in Tasmania.* Natural Heritage Trust Project NWP 11990, Nature Conservation Branch, Hobart: 123 pp.

Bryant, S.L. (ed) 2008: *Three Hummock Island: 2006 flora and fauna survey.* Hamish Saunders Memorial Trust, New Zealand and Resource Management & Conservation, DPIW, Hobart, Nature Conservation Report Series 08/03: 54 pp.

Bryant, S.L. 2014: Birds. *In* Hansen, A. & Davies, M. (eds): *Library at the End of the World: natural science and its illustrators.* Royal Society of Tasmania, Hobart: 148–168.

Bryant, S.L. & Carlyon, K. 2013: Birds of Inner Sister Island, Eastern Bass Strait. *Tasmanian Bird Report* **35**:1–6.

Bryant, S.L. & Copley, P.B. 2018: Partnerships for island conservation: it's all about people. *In* Moro, D., Ball, D. & Bryant, S.L. (eds): *Australian Island Arks: Conservation, Management and Opportunities.* CSIRO Publishing, Clayton South, Victoria: 177–190.

Bryant, S.L. & Jackson, J. 1999: *Tasmania's Threatened Fauna Handbook: Where, What and How to Conserve Tasmania's Threatened Animals.* Threatened Species Unit, Parks and Wildlife Service, Tasmanian Government Printer, Hobart: 426 pp. (https://dpipwe.tas.gov.au/conservation/threatened-species-and-communities/publications-forms-related-information/tasmanias-threatened-fauna-handbook).

Bryant, S.L. & Shaw, J. (eds) 2006: *Tasman Island: 2005 flora and fauna survey.* Hamish Saunders Memorial Trust, New Zealand and Biodiversity Conservation Branch, DPIW, Hobart, Nature Conservation Report Series 06/01: 49 pp.

Bryant, S.L. & Shaw. J.D. 2007: *Threatened species assessment on Macquarie Island, Voyage 5, April 2007.* Report to Biodiversity Conservation Branch, DPIW, Tasmania: 21 pp. (https://dpipwe.tas.gov.au/Documents/Macquarie-Island-Report-2007.pdf).

Carlyon, K., Pemberton, D. & Rudman, T. 2011: *Islands of the Hogan Group, Bass Strait: Biodiversity and Oil Spill Response Survey.* Resource Management and Conservation Division, DPIPWE, Hobart, Nature Conservation Report Series 11/03: 53 pp.

Carlyon, K., Visoiu, M., Hawkins, C., Richards, K. & Alderman, R. 2015: *Rodondo Island, Bass Strait: Biodiversity & Oil Spill Response Survey, January 2015.* Natural and Cultural Heritage Division, DPIPWE, Hobart. Nature Conservation Report Series 15/04: 59 pp.

Cochran, T. 2003: *Managing Threatened Species and Communities on Bruny Island.* Threatened Species Unit, Department of Primary Industries, Water and Environment, Tasmania: 172 pp.

Comfort, M. 2014: *Macquarie Island World Heritage Area Geoconservation Strategy.* Resource Management and Conservation Division, Department of Primary Industries, Parks, Water and Environment, Hobart. Nature Conservation Report Series 14/2: 48 pp.

de Salas, M.F. & Baker, M.L. 2018*: A Census of the Vascular Plants of Tasmania, including Macquarie Island.* Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Hobart: 156 pp.

Dixon, G. 1996: *A reconnaissance inventory of sites of geo-conservation significance on Tasmanian islands.* Report to Parks & Wildlife Service, Tasmania: 30 pp.

Donaghey, R. (ed.) 2003: *The fauna of King Island: A guide to identification and conservation management.* King Island Natural Resource Management Group Inc. King Island: 152 pp.

Driessen, M.M. & Hocking, G.J. 2008: *Review of Wildlife Monitoring Priorities. Nature Conservation Report 08/02.* Department of Primary Industries and Water, Tasmania: 58 pp.

DPIPWE 2010a: *Draft Recovery Plan for the Tasmanian Devil* (Sarcophilus harrisii). Department of Primary Industries, Parks, Water and Environment, Hobart: 55 pp. (https://dpipwe.tas.gov.au/Documents/Draft-Tasmanian-Devil-Recovery-Plan.pdf).

DPIPWE 2010b: *Vulnerability of Tasmania's natural environment to climate change: an overview.* Unpublished report. Resource Management and Conservation Division, Department of Primary Industries, Parks, Water and Environment, Hobart: 90 pp.

DPIPWE 2016: *Tasmanian Wilderness World Heritage Area Management Plan 2016,* Department of Primary Industries, Parks, Water and Environment, Hobart: 240 pp.

Eberhard, R. 2011: Geodiversity. *In* Harris, S. & Reid, A. (eds)*: Inner (West) Sister Island Scientific Expedition 2010.* Hamish Saunders Memorial Trust, New Zealand and Resource Management and Conservation Division, DPIPWE. Hobart, Nature Conservation Report Series 11/2: 19–26.

Eberhard, R. 2017: Aspects of geodiversity on Hunter Island: four Quaternary age Geosites. *In* Natural and Cultural Heritage Division: *South Hunter and Stack Island Natural and Cultural Values Survey.* Hamish Saunders Memorial Trust, New Zealand and the Natural and Cultural Heritage Division, DPIPWE. Hobart, Nature Conservation Report 17/4: 69–70.

Ecosure 2009: Prioritisation of high conservation status of offshore islands. Report to the Australian Government Department of the Environment, Water, Heritage and the Arts. Ecosure, Cairns, Queensland: 387 pp.

Fielding, M.W., Buettel, J.C. & Brook, B.W. 2020: Trophic rewilding of native extirpated predators on Bass Strait Islands could benefit woodland birds. *Emu - Austral Ornithology* **120(3)**: 260–262.

Gaston, A.J., Ydenberg, R.C. & Smith, G.E.J. 2007: Ashmole's halo and population regulation in seabirds. *Marine Ornithology* **35**: 119–126.

Grove, S. & de Little, R. 2014: The coastal marine mollusc fauna of King Island, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **148**: 17–42.

Harris, S. 2014: Vascular Plants. *In* Hansen, A. & Davies, M. (eds): *Library at the End of the World: natural science and its illustrators.* Royal Society of Tasmania, Hobart: 22–49.

Harris, S., Buchanan, A. & Connolly, A. 2001: *One Hundred Islands: The Flora of the Outer Furneaux.* DPIWE, Printing Authority of Tasmania, Hobart: 361 pp.

Harris, S. & McKenny, H. 1999: Preservation Island, Furneaux Group: two hundred years of vegetation change. *Papers and Proceedings of the Royal Society of Tasmania* **133(1)**: 85–101.

Harris, S. & Reid, A. (eds) 2011: *Inner (West) Sister Island Scientific Expedition 2010.* Hamish Saunders Memorial Trust, New Zealand and Resource Management and Conservation Division, DPIPWE, Hobart, Nature Conservation Report Series 11/2: 140 pp.

Harris, S. & Lazarus, E. 2006: Ecological observations on a remote montane occurrence of *Bedfordia arborescens* (Asteraceae), Cape Barren Island, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **140**: 35–48.

Harris, S., Ziegler, K. & Dell, M. 2015: The vegetation and flora of Strzelecki National Park, Flinders Island, Tasmania. *Cunninghamia* **15**: 163–184.

Helmstedt, K.J., Shaw, J.D., Bode, M., Terauds, A., Springer, K., Robinson, S.A. & Possingham, H. 2016: Prioritizing eradication actions on islands: it's not all or nothing. *Journal of Applied Ecology* **53**: 733–741.

Jennings, J.N. 1959: The coastal geomorphology of King Island, Bass Strait, in relation to change in the relative level of land and sea. *Records of the Queen Victoria Museum, Launceston* **11**: 1–37.

Kirkpatrick, J.B. & Harwood, C.E. 1983: Plant communities of Tasmanian wetlands. *Australian Journal of Botany* **31**: 437–451.

Kirkwood, J. & O'Connor, J. (eds) 2010: The state of Australia's birds 2010: islands and birds. *Supplement to Wingspan* **20(4)**: 52 pp.

Kirkwood, R., Pemberton, D., Gales, R., Hoskins, A.J., Mitchell, T., Shaughnessy, P.D. & Arnould, J.P.Y. 2010: Continued population recovery by Australian fur seals. *Marine and Freshwater Research* **61**: 695–701.

Lohr, C.A., Baker, C.M., Bode, M. & Pressey, R.L. 2018: What's next on the list? Prioritising management actions on Australia's islands. *In* Moro, D., Ball, D. & Bryant, S.L. (eds): *Australian Island Arks: Conservation, Management and Opportunities.* CSIRO Publishing, Clayton South, Victoria: 71–84.

McWethy, D.B., Haberle, S.G., Hopf, F. & Bowman, D.M.J.S. 2017: Aboriginal impacts on fire and vegetation on a Tasmanian island. *Journal of Biogeography* **44(6)**: 1319–1330.

Mallick, S.A. & Driessen, M.M. 2009: *Review, risk assessment and management of introduced animals in the Tasmanian Wilderness World Heritage Area.* Nature Conservation Report 10/01. Department of Primary Industries, Parks, Water and Environment, Tasmania: 66 pp.

Mallon, K. 2007: Climate change impacts on marine and coastal birds. *Waves* **13**: 10.

Mesibov, R. 2019: Times have changed for field work in Tasmania. *The Tasmanian Naturalist* 141: 137–143.

Moro, D., Ball, D. & Bryant, S.L. (eds) 2018: *Australian Island Arks: Conservation, management and opportunities.* CSIRO Publishing, Clayton South, Victoria: 264 pp.

National Parks & Wildlife Service 1972: Report for the year ended 1972. Report presented to both Houses of Parliament pursuant to section 6 of the National Parks and Wildlife Act 1970. Government Printer, Hobart: 114 pp.

NCHD Natural & Cultural Heritage Division 2014: Flinders Island: Natural Values Survey 2012. Hamish Saunders Memorial Trust, New Zealand and Natural and Cultural Heritage Division, DPIPWE, Hobart. Nature Conservation Report Series 14/1: 134 pp.

Parsons, K.E. 2011: *Nowhere Else on Earth: Tasmania's Marine Natural Values.* Report for Environment Tasmania. Aquenal, Tasmania: 102 pp.

Pfennigwerth, S. 2008: *Feral Animals of Tasmania.* WorldWide Fund for Nature Australia, Threatened Species Network, Hobart: 62 pp.

Polis, G.A. & Hurd, S.D. 1996: Linking marine and terrestrial food webs: allochthonous input from the ocean supports high secondary productivity on small islands and coastal land communities. *American Naturalist* **147(3)**: 396–423.

Prahalad, V., Kirkpatrick, J. & Mount, R. 2012: Tasmanian coastal salt marsh community transitions associated with climate change and relative sea level rise 1975-2009. *Australian Journal of Botany* **59**: 741–748.

Prahalad, V. & Pearson, J. 2013: *Southern Tasmanian Saltmarsh Futures: A Preliminary Strategic Assessment.* NRM South, Hobart, Tasmania: 73 pp.

PWS 1998: *Maria Island National Park and Ile des Phoques Nature Reserve Management Plan 1998.* Parks and Wildlife Service, Tasmania: 120 pp.

PWS 2006: *Macquarie Island Nature Reserve and World Heritage Area Management Plan.* Parks and Wildlife Service. Department of Tourism, Arts and the Environment, Hobart: 207 pp.

Robinson, S. & Dick, W. 2020: Black rats eradicated from Big Green Island in Bass Strait, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **154**: 37–46.

Robinson, S. & Gadd, L. 2020: Unviable feral cat population results in eradication success on Wedge Island, Tasmania. *Papers and Proceedings Royal Society* **154:** 47–50.

Robinson, S., Gadd, L., Johnston, M. & Pauza, M. 2015: Long-term protection of important seabird breeding colonies on Tasman Island through eradication of cats. *New Zealand Journal of Ecology* **39(2)**: 316–322.

Rounsevell, D. 1989: Managing offshore island reserves for nature conservation in Tasmania. *In* Burbidge, A. (ed): *Australian and New Zealand islands: nature conservation values and management.* Department of Conservation and Land Management, Perth, Western Australia: 157–161.

RPDC 2006: *State of the Environment Tasmania.* Resource Planning and Development Commission last modified 14 December 2006 (http//www.rpdc.tas.gov. au/RPDCr).

Secretariat of the Convention on Biological Diversity 2014: Island Biodiversity – Island Bright Spots in Conservation & Sustainability. Secretariat of the Convention on Biological Diversity, Montreal, Canada: 92 pp. (www.unenvironment.org/resources/report/island-biodiversity-island-bright-spots-conservation-sustainability).

Selkirk, P.M., Seppelt, R.D. & Selkirk, D.R. (1990) *Subantarctic Macquarie Island: environment and biology.* Cambridge University Press, Cambridge: 285 pp.

Seymour, D.B., Green, G.R. & Calver, C.R. 2007: *The geology and mineral deposits of Tasmania: a summary.* Geological Survey Bulletin 72. Mineral Resources Tasmania, Department of Infrastructure, Energy and Resources, Tasmania: 32 pp.

Sharples, C. 2006: Indicative mapping of Tasmanian coastal vulnerability to climate change and sea-level rise: Explanatory report (second edn). Consultant Report to Department of Primary Industries & Water, Hobart, Tasmania: 173 pp.

Springer, K. 2018: Island pest management. *In* Moro, D., Ball, D. & Bryant, S.L. (eds): *Australian Island Arks: Conservation, Management and Opportunities.* CSIRO Publishing, Clayton South, Victoria: 85–98.

Statham, M. & Middleton, M. 1987: Feral pigs on Flinders Island. *Papers and Proceedings of the Royal Society of Tasmania* **121**: 121–124.

Tasmanian Planning Commission 2009: State of the Environment Report: Tasmania 2009. Tasmanian Planning Commission, Tasmania: 20 pp. (www.planning.tas.gov.au/__data/

assets/pdf_file/0006/332736/State_of_the_Environment_overview_2009.pdf)

TASMAP 2006: Islands of Tasmania Map Scale 1:600,000 TASMAP Production. State Government of Tasmania, Hobart, Tasmania.

Terauds, A. 2005: *Introduced animals on Tasmanian Islands.* Biodiversity Conservation Branch, Department of Primary Industries, Water and Environment (DPIWE), Hobart, Tasmania: 19 pp.

Terauds, A. & Stewart, F. 2009: *Subantarctic Wilderness: Macquarie Island.* Allen & Unwin, NSW: 176 pp.

Threatened Species Unit 2001: *Pedra Branca Skink Recovery Plan.* Department of Primary Industries, Water and Environment (DPIWE), Hobart: 22 pp.

TLC 2019: Newsletter No 60 Tasmanian Land Conservancy (https://tasland.org.au/content/uploads/2019/12/NL60_TLC-WEB.pdf).

TPC 2009: Natural values chapter and introduced species on offshore islands indicator. State of the Environment Report: Tasmania 2009. Tasmanian Planning Commission, Tasmania: 20 pp. (https://epa.tas.gov.au/epa/air/legislative-context-air-quality-in-tasmania/state-of-the-environment-reports)

TSS 2012: *King Island Biodiversity Management Plan.* Threatened Species Section, Department of Primary Industries, Parks, Water and Environment (DPIPWE), Hobart: 144 pp.

Webb, M.H., Holdsworth, M., Stojanovic, D., Terauds, A., Bell P. & Heinsohn, R. 2016: Immediate action required to prevent another Australian avian extinction: the King Island Scrubtit. *Emu* **116**: 223–229.

Whinam, J. & Shaw, J.D. 2018: Australia's World Heritage islands. *In* Moro, D., Ball, D. & Bryant, S.L. (eds): *Australian Island Arks: Conservation, Management and Opportunities.* CSIRO Publishing, Clayton South, Victoria: 147–164.

Wildlife Management Branch 2010: *Game Tracks Issue 15.* Department of Primary Industries, Parks, Water and Environment (DPIPWE), Hobart: 60 pp.

Williamson, P.E. 1988: Origin, structural and tectonic history of the Macquarie Island region. *Papers and Proceedings of the Royal Society of Tasmania* **122(1)**: 27–43.

Wise, P., Lee, D., Peck, S., Clarke, J., Thalmann, S., Hockley, J., Schaap, D. & Pemberton, D. 2016: The conservation introduction of Tasmanian devils to Maria Island National Park: A response to Devil Facial Tumour Disease (DFTD). *In* Soorae, P.S. (ed.): *Global Re-introduction Perspectives: 2016. Case studies From Around the Globe.* Gland, Switzerland: 166–171.

Woehler, E.J. & Ruoppolo, V. 2010: Shorebirds and seabirds of Flinders and King Islands. *In* Kirkwood, J. & J. O'Connor, J. (eds): *The state of Australia's birds 2010: islands and birds. Supplement to Wingspan* **20(4)**: 10–11.

Woinarski, J.C.Z., Burbidge, A.A. & Reside, A.E. 2018: Enhancing island conservation outcomes: the policy and legal context, need, and options. *In* Moro, D., Ball, D. & Bryant, S.L. (eds): *Australian Island Arks: Conservation, Management and Opportunities.* CSIRO Publishing, Clayton South, Victoria: 45–60.

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APPENDIX 1 — Threatened Land-based fauna recorded on Tasmania's offshore islands.

Species identified from (https://dpipwe.tas.gov.au/conservation/threatened-species-and-communities/lists-of-threatened-species/full-list-of-threatened-species; last updated 16 July 2020). Status in Tasmania TAS on the Threatened Species Protection Act 1995 and Commonwealth CW status refers to listings under the Environment Protection and Biodiversity Conservation Act 1999. Status code: CR critically endangered, e, EN endangered, x, EX extinct, v, VU vulnerable, r rare. Accuracy of distribution records on the Natural Values Atlas (Department of Primary Industries, Water and Environment, accessed 20 Oct 2020), is variable for many species (https://dpipwe.tas.gov.au/conservation/development-planning-conservation-assessment/planning-tools/natural-values-atlas). See notes below for more information.

Vertebrate species[1]	Common name	Group	Status TAS	Status CW	Key island or group[2]
Arctocephalus forsteri	Long-nosed (NZ) Fur Seal	MAMMALS	r	-	Macquarie, Maatsuyker, Flat Witch, Tasman, Taillefer Rocks, Ile des Phoques, Cape Raoul, Cape Pillar, Wendar and others in Bass Strait
Arctocephalus tropicalis	Subantarctic Fur Seal	MAMMALS	e	EN	Macquarie and occasionally elsewhere
Dasyurus maculatus	Spotted-tailed Quoll	MAMMALS	r	VU	King (now extinct)[3]
Dasyurus viverrinus	Eastern Quoll	MAMMALS	-	EN	Bruny[4]
Mirounga leonina	Southern Elephant Seal	MAMMALS	e	VU	Macquarie, Maatsuyker, Bruny, King, Forsyth and occasionally elsewhere
Perameles gunnii gunnii	Eastern-barred Bandicoot	MAMMALS	-	VU	Bruny[4]
Pseudomys novaehollandiae	New Holland Mouse	MAMMALS	e	VU	Flinders
Sarcophilus harrisii	Tasmanian Devil	MAMMALS	e	EN	Robbins, Maria
Acanthiza pusilla archibaldi	Brown Thornbill (King Is)	BIRDS	e	EN	King
Acanthornis magna greeniana	Scrubtit (King Island)	BIRDS	e	CR	King
Accipiter novaehollandiae	Grey Goshawk	BIRDS	e	-	Bruny[5], may be elsewhere
Aquila audax fleayi	Wedge-tailed Eagle	BIRDS	e	EN	Many islands inc Bruny

APPENDIX 1 – cont.

Vertebrate species[1]	Common name	Group	Status TAS	Status CW	Key island or group[2]
Botaurus poiciloptilus	Australasian Bittern	BIRDS	-	EN	King, Flinders, Bruny[5]
Calidris ferruginea	Curlew Sandpiper	BIRDS	-	CR	King, Perkins, Furneaux Group, occasionally elsewhere
Ceyx azureus diemenensis	Tasmanian Azure Kingfisher	BIRDS	e	EN	Flinders, King, Bruny, occasionally elsewhere
Cyanoramphus novaezelandiae erythrotis	Macquarie Island Parakeet	BIRDS	x	EX	Macquarie[6]
Diomedea exulans	Wandering Albatross	BIRDS	e	VU	Macquarie[6]
Dromaius minor	King Island Emu	BIRDS	x	EX	King
Gallirallus philippensis macquariensis	Macquarie Island Rail	BIRDS	x	EX	Macquarie[6]
Haliaeetus leucogaster	White-bellied Sea-Eagle	BIRDS	v	-	Many islands including King, Flinders, Maria, Bruny and Maatsuyker Group
Halobaena caerulea	Blue Petrel	BIRDS	v	VU	Macquarie[6]
Lathamus discolor	Swift Parrot	BIRDS	e	CR	Maria, Bruny, Flinders, Partridge, possibly elsewhere
Leucocarbo atriceps purpurascens	Macquarie Island Shag	BIRDS	v	VU	Macquarie[6]
Macronectes giganteus	Southern Giant Petrel	BIRDS	v	EN	Macquarie[6], occasionally elsewhere
Macronectes halli	Northern Giant Petrel	BIRDS	r	VU	Macquarie[6], occasionally elsewhere
Neophema chrysogaster	Orange-bellied Parrot	BIRDS	e	CR	King, possibly others in Boullanger Bay, Bruny (historic)[5]
Numenius madagascariensis	Eastern Curlew	BIRDS	e	CR	Flinders, King, Bruny, Robbins, Kangaroo, recorded elsewhere
Oceanites oceanicus	Wilson's Storm Petrel	BIRDS	r	-	Macquarie[6]
Pachyptila turtur subantarctica	Fairy Prion southern sub-species	BIRDS	e	VU	Macquarie[6]
Pardalotus quadragintus	Forty-spotted Pardalote	BIRDS	e	EN	King (extinct)[3], Flinders, Maria, Bruny, Partridge
Phoebetria fusca	Sooty Albatross	BIRDS	r	VU	Macquarie[6]
Phoebetria palpebrata	Light-mantled Albatross	BIRDS	v	-	Macquarie[6]
Platycercus caledonicus brownii	King Island Green Rosella	BIRDS	v	VU	King
Procellaria cinerea	Grey Petrel	BIRDS	e	-	Macquarie[6]
Pterodroma lessonii	White-headed Petrel	BIRDS	v	-	Macquarie[6]
Pterodroma mollis	Soft-plumaged Petrel	BIRDS	e	VU	Macquarie[6], Maatsuyker
Sterna striata	White-fronted Tern	BIRDS	v	-	Mainly islands in the Furneaux including truwana-Cape Barren, also Albatross and elsewhere
Sterna vittata bethunei	Antarctic Tern	BIRDS	e	EN	Macquarie[6]
Sternula albifrons sinensis	Little Tern	BIRDS	e	-	King, Flinders, islands in Bass Strait and Boullanger Bay
Sternula nereis nereis	Fairy Tern	BIRDS	v	VU	King, Flinders, islands in Bass Strait and Boullanger Bay and elsewhere
Strepera fuliginosa colei	Black Currawong (King Is)	BIRDS	-	VU	King
Thalassarche cauta	Shy Albatross	BIRDS	v	EN	Albatross, Pedra Branca, Mewstone, occasionally elsewhere

APPENDIX 1 – cont.

Vertebrate species[1]	Common name	Group	Status TAS	Status CW	Key island or group[2]
Thalassarche chrysostoma	Grey-headed Albatross	BIRDS	e	EN	Macquarie[6], occasionally elsewhere
Thalassarche melanophris	Black-browed Albatross	BIRDS	e	VU	Macquarie[6], occasionally elsewhere
Thinornis cucullatus cucullatus	Hooded Plover (Eastern)	BIRDS	-	VU	Many islands including King, Flinders, Bruny, Maria and in Bass Strait
Tyto novaehollandiae castanops	Masked Owl	BIRDS	e	VU	Bruny[5], Maria, Trefoil, Betsey, occasionally elsewhere
Litoria raniformis	Green and Gold Frog	AMPHIBIANS	v	VU	King, Flinders, Maria
Limnodynastes peroni	Striped Marsh Frog	AMPHIBIANS	e	-	King
Carinascincus palfreymani	Pedra Branca Skink	REPTILES	e	VU	Pedra Branca
Pseudemoia rawlinsoni	Glossy Grass Skink	REPTILES	r	-	truwana-Cape Barren, Picnic?
Pseudemoia pagenstecheri	Tussock Skink	REPTILES	v	-	truwana-Cape Barren
Galaxiella pusilla	Dwarf Galaxias	FISH	v	VU	Flinders

Invertebrate species	Common name	Order	Status TAS	Status CW	Island or group
Austrorhytida lamproides	Keeled Snail	SIGMURETHRA	r	-	Three Hummock
Cavernotettix craggiensis	Craggy Island Cave Cricket	ORTHOPTERA	r	-	Craggy (north west of Flinders)
Chloritobadistes victoriae	Southern Hairy Red Snail	EUPULMONATA	v	-	King
Dasyurotaenia robusta	Tapeworm (Tasmanian Devil)	CYCLOPHYLLIDEAE	r	-	Robbins, Maria
Echinodillo cavaticus	Flinders Island Cave Slater	ISOPODA	r	-	Flinders
Engaeus martigener	Furneaux Burrowing Crayfish	DECAPODA	v	EN	Flinders, truwana-Cape Barren
Lissotes latidens	Broad-toothed Stag Beetle	COLEOPTERA	e	EN	Maria
Lissotes menalcas	Mt. Mangana Stag Beetle	COLEOPTERA	r	-	Bruny
Parvotettix rangaensis	Cave Cricket	ORTHOPTERA	r	-	truwana-Cape Barren
Parvotettix whinrayi	Whinray's Cave Cricket	ORTHOPTERA	r	-	Flinders
Theclinesthes serpentata	Chequered Blue	LEPIDOPTERA	r	-	Flinders, Diamond

[1] Table does not include Grey-headed Flying-fox *Pteropus poliocephalus*, or Great Knot *Calidris tenuirostris* (listed on EPBC but not on https://dpipwe.tas.gov.au/conservation/threatened-species-and-communities/lists-of-threatened-species/full-list-of-threatened-species) or White-throated Needletail *Hirundapus caudacutus* as mainly arboreal

[2] Only main islands mentioned and may be recorded on islands elsewhere.

[3] Additional reference for Spotted-tailed Quoll and Forty-spotted Pardalote: **Donaghey, R.** (ed.) 2003: The fauna of King Island: A guide to identification and conservation management. King Island Natural Resource Management Group Inc. King Island: 152 pp.

[4] Additional reference for Eastern Quoll and Eastern-barred Bandicoot: **Driessen, M.M., Carlyon, K., Gales, R., Mooney, N., Pauza, M., Thurstans, S., Visoiu, M. & Wise, P.** 2011: Terrestrial mammals of a sheep-grazing property on Bruny Island, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 145: 51-64.

[5] Birds on Bruny Island supported by the checklist: https://www.brunybirdfestival.org.au/images/downloads/Bird_Festival_2018_-_Checklist_of_bird_species_found_on_Bruny_Island.pdf

[6] Macquarie Island species source https://avibase.bsc-eoc.org/checklist.jsp?region=AUmi&list=howardmoore (accessed 1 October 2020).

APPENDIX 2 — Threatened flora species recorded on Tasmania's offshore islands.[1]

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Acacia ulicifolia	Juniper Wattle	Fabaceae	rare		Flinders Island; Three Hummock Island; Bruny Island
Acrotriche cordata	Coast Groundberry	Ericaceae	vulnerable		Prime Seal Island; Flinders Island
Allocasuarina crassa	Cape Pillar Sheoak	Casuarinaceae	rare		Tasman Island
Allocasuarina duncanii	Conical Sheoak	Casuarinaceae	rare		Bruny Island
Aphelia gracilis	Slender Fanwort	Centrolepidaceae	rare		Flinders Island
Asperula minima	Mossy Woodruff	Rubiaceae	rare		Inner Sister Island; Vansittart Island; Inner Sister Island; Flinders Island
Asperula scoparia var. *scoparia*	Prickly Woodruff	Rubiaceae	rare		Bruny Island
Asperula subsimplex	Water Woodruff	Rubiaceae	rare		Flinders Island
Atriplex suberecta	Sprawling Saltbush	Amaranthaceae	vulnerable		Little Chalky Island; Wybalenna Island; Boxen Island; Badger Island; Beagle Island; Little Badger Island; Outer Green Island
Australina pusilla subsp. *muelleri*	Shade Nettle	Urticaceae	rare		King Island
Austrodanthonia remota	Remote Wallabygrass	Poaceae	rare		Hibbs Pyramid
Austrostipa bigeniculata	Doublejointed Speargrass	Poaceae	rare		Anderson Islands
Austrostipa blackii	Crested Speargrass	Poaceae	rare		Bruny Island
Azorella macquariensis	Macquarie Cushions	Apiaceae	endangered	Critically endangered	Macquarie Island
Banksia integrifolia	Coast Banksia	Proteaceae	extinct		Long Island; Hogan Group
Banksia serrata	Saw Banksia	Proteaceae	rare		Flinders Island
Baumea gunnii	Slender Twigsedge	Cyperaceae	rare		Schouten Island, Flinders Island
Bedfordia arborescens	Tree Blanketleaf	Asteraceae	vulnerable		Cape Barren Island
Bolboschoenus caldwellii	Sea Clubsedge	Cyperaceae	rare		King Island
Bolboschoenus medianus	Marsh Clubsedge	Cyperaceae	rare		King Island
Brachyloma depressum	Spreading Heath	Ericaceae	rare		Flinders Island; Clarke Island; Schouten Island
Brachyscome perpusilla	Tiny Daisy	Asteraceae	rare		Flinders Island
Caladenia aurantiaca	Orangetip Fingers	Orchidaceae	endangered		Deal Island
Caladenia australis	Southern Spider-Orchid	Orchidaceae	endangered		Flinders Island
Caladenia brachyscapa	Short Spider-Orchid	Orchidaceae	endangered	Extinct	Clarke Island; Cape Barren Island
Caladenia cardiochila	Heartlip Spider-Orchid	Orchidaceae	extinct		Flinders Island
Caladenia caudata	Tailed Spider-Orchid	Orchidaceae	vulnerable	Vulnerable	Bruny Island; Schouten Island; Clarke Island; Cape Barren Island; Flinders Island
Caladenia filamentosa var. *filamentosa*	Daddy Longlegs	Orchidaceae	rare		Bruny Island; Schouten Island; Flinders Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Caladenia prolata	White Fingers	Orchidaceae	endangered		Deal Island; Flinders Island
Caladenia pusilla	Tiny Fingers	Orchidaceae	rare		King Island; Three Hummock Island; Cape Barren Island; Flinders Island; Deal Island
Calandrinia granulifera	Pygmy Purslane	Portulacaceae	rare		Cape Barren Island; Flinders Island
Callitriche sonderi	Matted Waterstarwort	Plantaginaceae	rare		King Island
Calochilus campestris	Copper Beard-Orchid	Orchidaceae	endangered		Cape Barren Island; Clarke Island
Calystegia marginata	Forest Bindweed	Convolvulaceae	endangered		Cape Barren Island
Calystegia soldanella	Sea Bindweed	Convolvulaceae	rare		Bruny Island; King Island; East Kangaroo Island; Anderson Islands
Carex gunniana	Mountain Sedge	Cyperaceae	rare		Bruny Island
Caustis pentandra	Thick Twistsedge	Cyperaceae	rare		Schouten Island
Centipeda cunninghamii	Erect Sneezeweed	Asteraceae	rare		King Island
Centrolepis strigosa subsp. *pulvinata*	Bassian Bristlewort	Centrolepidaceae	rare		Cape Barren Island, Hogan Island; Deal Island
Chenopodium erosum	Papery Goosefoot	Amaranthaceae	extinct		Kent Group
Chiloglottis trapeziformis	Broadlip Bird-Orchid	Orchidaceae	endangered		Flinders Island; Great Dog Island
Chiloglottis valida	Large Bird-Orchid	Orchidaceae	listing as endangered pending (unofficial)		King Island
Chrysocephalum baxteri	Fringed Everlasting	Asteraceae	rare		Clarke Island; Cape Barren Island; Flinders Island
Comesperma defoliatum	Leafless Milkwort	Polygalaceae	rare		Cape Barren Island, King Island
Conospermum hookeri	Tasmanian Smokebush	Proteaceae	vulnerable	Vulnerable	Bruny Island; Cape Barren Island; Schouten Island
Corybas dienemus	Windswept Helmet-Orchid	Orchidaceae	vulnerable	Critically endangered	Macquarie Island; Flinders Island; King Island
Corybas fordhamii	Swamp Pelican-Orchid	Orchidaceae	endangered		Flinders Island
Corybas sulcatus	Grooved Helmet-Orchid	Orchidaceae	endangered	Critically endangered	Macquarie Island
Cotula vulgaris var. *australasica*	Slender Buttons	Asteraceae	rare		King Island; Three Hummock Island; Cape Barren Island; Passage Island; Inner Sister Island; Flinders Island; Hogan Island; Deal Island
Crassula moschata	Musky Stonecrop	Crassulaceae	rare		Macquarie Island; King Island; Black Pyramid; Albatross Island; Trefoil Island; Vansittart Island; Curtis Island; Bruny Island; Gull Reef Port Davey
Cryptandra exilis	Slender Pearlflower	Rhamnaceae	listing as vulnerable under consideration (unofficial)		Schouten Island; Cape Barren Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Cryptostylis leptochila	Small Tongue-Orchid	Orchidaceae	endangered		Flinders Island; Cape Barren Island
Cuscuta tasmanica	Golden Dodder	Convolvulaceae	rare		Flinders Island
Cyathea cunninghamii	Slender Treefern	Cyatheaceae	endangered		King Island
Cyathea Xmarcescens	Skirted Treefern	Cyatheaceae	endangered		King Island
Cyathodes platystoma	Tall Cheeseberry	Ericaceae	rare		Bruny Island
Cyphanthera tasmanica	Tasmanian Rayflower	Solanaceae	rare		Maria Island; Schouten Island
Cyrtostylis robusta	Large Gnat-Orchid	Orchidaceae	rare		Flinders Island; West Sister Island; Prime Seal Island; Hunter Island; King Island; Deal Island
Desmodium gunnii	Southern Ticktrefoil	Fabaceae	vulnerable		Schouten Island
Deyeuxia minor	Small Bentgrass	Poaceae	rare		Bruny Island
Diuris palustris	Swamp Doubletail	Orchidaceae	endangered		Flinders Island
Drosera glanduligera	Scarlet Sundew	Droseraceae	rare		Flinders Island
Elaeocarpus reticulatus	Blueberry Ash	Elaeocarpaceae	rare		Flinders Island; King Island
Epacris barbata	Bearded Heath	Ericaceae	endangered	Endangered	Schouten Island
Epacris virgata (Kettering)	Pretty Heath	Ericaceae	vulnerable (unofficial)		Bruny Island
Epilobium pallidiflorum	Showy Willowherb	Onagraceae	rare, delisting pending		King Island; Hunter Island
Eucalyptus globulus subsp. globulus	Gippsland Blue Gum	Myrtaceae	rare		Flinders Island; Inner Sister Island; Rodondo Island
Euphrasia collina subsp. *deflexifolia*	Eastern Eyebright	Orobanchaceae	rare		Schouten Island
Euphrasia fragosa	Shy Eyebright	Orobanchaceae	endangered	Critically endangered	Bruny Island
Eutaxia microphylla	Spiny Bushpea	Fabaceae	rare		Prime Seal Island; Flinders Island; Cape Barren Island
Frankenia pauciflora var. *gunnii*	Southern Seaheath	Frankeniaceae	rare		Harcus Island, Short Island; Little Goose Island; Preservation Island; Spike Island; Clarke Island; Rum Island; Cone Island
Galium antarcticum	Subantarctic Bedstraw	Rubiaceae	endangered	Critically endangered	Macquarie Island
Geococcus pusillus	Earth Cress	Brassicaceae	rare		Mount Chappell Island; Little Chalky Island; Mile Island; King Island
Gompholobium ecostatum	Dwarf Wedgepea	Fabaceae	endangered		Flinders Island
Gratiola pubescens	Hairy Brooklime	Plantaginaceae	rare		King Island; Cape Barren Island; Bruny Island
Gynatrix pulchella	Fragrant Hempbush	Malvaceae	rare		Flinders Island; Cape Barren Island; Maria Island
Gyrostemon thesioides	Broom Wheelfruit	Gyrostemonaceae	rare		Deal Island; Flinders Island; Cape Barren Island; Clarke Island
Hackelia latifolia	Forest Houndstongue	Boraginaceae	rare		King Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Hakea ulicina	Furze Needlebush	Proteaceae	vulnerable		Flinders Island; Cape Barren; Clarke Island
Haloragis myriocarpa	Prickly Raspwort	Haloragaceae	rare		Flinders Island; Clarke Island; Cape Barren Island; King Island
Hedycarya angustifolia	Australian Mulberry	Monimiaceae	rare		King Island
Hibbertia obtusifolia	Grey Guineaflower	Dilleniaceae	extinct		Clarke Island
Hydrocotyle comocarpa	Fringefruit Pennywort	Araliaceae	rare		Flinders Island; Cape Barren; Deal Island
Hydrorchis orbicularis	Swamp Onion-Orchid	Orchidaceae	rare		Bruny Island; Clarke Island; Cape Barren Island; Flinders Island
Hypolepis distans	Scrambling Groundfern	Dennstaedtiaceae	endangered	Endangered	King Island
Hypolepis muelleri	Harsh Groundfern	Dennstaedtiaceae	rare		Flinders Island; King Island
Isoetes drummondii subsp. drummondii	Plain Quillwort	Isoetaceae	rare		Flinders Island
Isopogon ceratophyllus	Horny Conebush	Proteaceae	vulnerable		Cape Barren Island; Flinders Island; Clarke Island
Juncus amabilis	Gentle Rush	Juncaceae	rare, delisting pending		Bruny Island
Juncus prismatocarpus	Branching Rush	Juncaceae	rare		Bruny Island
Juncus vaginatus	Clustered Rush	Juncaceae	rare		Wedge Island
Lachnagrostis billardierei subsp. *tenuiseta*	Small-Awn Blowngrass	Poaceae	rare		Flinders Island; Forsyth Island; Passage Island
Lachnagrostis robusta	Tall Blowngrass	Poaceae	rare		Cape Barren Island; Gull Reef Port Davey; Celery Top Islands; Maria Island; Cape Barren Island; Flinders Island
Lasiopetalum baueri	Slender Velvetbush	Malvaceae	rare		Flinders Island
Lasiopetalum discolor	Coast Velvetbush	Malvaceae	rare		Prime Seal Island; Cape Barren Island
Lepidium flexicaule	Springy Peppercress	Brassicaceae	rare		Bruny Island; Three Hummock; Gull Reef Port Davey; Black Swan Island; Muttonbird Island
Lepidosperma forsythii	Stout Rapiersedge	Cyperaceae	rare		Schouten Island; Cape Barren Island
Lepidosperma tortuosum	Twisting Rapiersedge	Cyperaceae	rare		Clarke Island
Lepidosperma viscidum	Sticky Swordsedge	Cyperaceae	rare		Bruny Island
Lepilaena patentifolia	Spreading Watermat	Potamogeton-aceae	rare		Flinders Island; King Island
Lepilaena preissii	Slender Watermat	Potamogeton-aceae	rare		Flinders Island
Leucopogon affinis	Lanceleaf Beardheath	Ericaceae	rare		King Island; Three Hummock Island; Clarke Island; Cape Barren Island; Flinders Island
Leucopogon esquamatus	Swamp Beardheath	Ericaceae	rare		Flinders Island; Cape Barren Island
Levenhookia dubia	Hairy Stylewort	Stylidiaceae	extinct		Flinders Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Limonium australe	Yellow Sea-Lavender	Plumbaginaceae	rare		Harcus Island, Short Island; Perkins Island
Lobelia pratioides	Poison Lobelia	Campanulaceae	vulnerable		Flinders Island
Lotus australis	Australian Trefoil	Fabaceae	rare		Flinders Island; Swan Island; Foster Island; Trefoil Island; Three Hummock Island
Microtis atrata	Yellow Onion-Orchid	Orchidaceae	rare		Bruny Island, Cape Barren Island and Flinders Island
Myoporum parvifolium	Creeping Boobialla	Scrophulariaceae	vulnerable		Flinders Island
Myriophyllum muelleri	Hooded Watermilfoil	Haloragaceae	rare		King Island; Long Island; Vansittart Island; Cape Barren Island, Clarke Island
Orthoceras strictum	Horned Orchid	Orchidaceae	rare		King Island; Schouten Island; Clarke Island; Cape Barren Island; Flinders Island
Pandorea pandorana	Wonga Vine	Bignoniaceae	rare		Flinders Island
Parietaria debilis	Shade Pellitory	Urticaceae	rare		King Island; Three Hummock Island; Erith Island, Deal Island, Rodondo Island; West Sister Island; Prime Seal Island; Great Dog Island; Puncheon Island; Little Green Island; Passage Island; Babel Island; Mount Chappell Island; Swan Island; Bruny Island
Pellaea calidirupium	Hotrock Fern	Adiantaceae	rare		Deal Island
Persicaria decipiens	Slender Waterpepper	Polygonaceae	vulnerable		King Island
Phyllangium distylis	Tiny Mitrewort	Loganiaceae	rare		Flinders Island; Cape Barren Island; King Island
Phyllangium divergens	Wiry Mitrewort	Loganiaceae	vulnerable		Bruny Island; Clarke Island; Cape Barren Island
Phylloglossum drummondii	Pygmy Clubmoss	Lycopodiaceae	rare		King Island, Cape Barren Island and Flinders Island
Pimelea axiflora subsp. *axiflora*	Bootlace Bush	Thymelaeaceae	endangered		King Island
Pimelea curviflora	Curved Riceflower	Thymelaeaceae	parent species (unofficial)		Schouten Island; Flinders Island; Badger Island
Pimelea micrantha	Silky Curved Riceflower	Thymelaeaceae	rare		Flinders Island
Pneumatopteris pennigera	Lime Fern	Thelypteridaceae	endangered		King Island
Poa cookii	Cooks Tussockgrass	Poaceae	endangered		Macquarie Island
Poa halmaturina	Dune Tussockgrass	Poaceae	rare		Clarke Island; Flinders Island
Podotheca angustifolia	Sticky Longheads	Asteraceae	extinct		King Island
Polystichum vestitum	Prickly Shieldfern	Dryopteridaceae	endangered		Macquarie Island
Pomaderris intermedia	Lemon Dogwood	Rhamnaceae	rare		Flinders Island; Cape Barren Island; Schouten Island
Pomaderris oraria subsp. *oraria*	Bassian Dogwood	Rhamnaceae	rare		Flinders Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Pomaderris paniculosa subsp. paralia	Shining Dogwood	Rhamnaceae	rare		King Island; Erith Island; Hogan Island, Prime Seal Island; Outer Sister Island; Swan Island; East Sister Island
Prasophyllum apoxychilum	Tapered Leek-Orchid	Orchidaceae	vulnerable	Endangered	Bruny Island
Prasophyllum atratum	Three Hummock Leek-Orchid	Orchidaceae	endangered	Critically Endangered	Three Hummock Island; Hunter Island
Prasophyllum castaneum	Chestnut Leek-Orchid	Orchidaceae	endangered	Critically Endangered	Bruny Island
Prasophyllum secutum	Northern Leek-Orchid	Orchidaceae	endangered	Endangered	Cape Barren Island, Flinders Island; Hunter Island; Robbins Island
Pterostylis cucullata	Leafy Greenhood	Orchidaceae	endangered	Vulnerable	King Island; Hunter Island; Three Hummock Island; Flinders Island
Pterostylis lustra	Small Sickle Greenhood	Orchidaceae	endangered		Perkins Island
Pterostylis sanguinea	Banded Greenhood	Orchidaceae	rare		Cape Barren Island; Clarke Island; Flinders Island; Deal Island
Pterostylis squamata	Ruddy Greenhood	Orchidaceae	vulnerable		Bruny Island
Pterostylis tunstallii	Tunstalls Greenhood	Orchidaceae	endangered		Vansittart Island; Flinders Island; Swan Island
Ranunculus diminutus	Brackish Buttercup	Ranunculaceae	endangered		Badger Island
Ranunculus pumilio var. *pumilio*	Ferny Buttercup	Ranunculaceae	rare		Flinders Island
Scaevola albida	Pale Fanflower	Goodeniaceae	vulnerable		Flinders Island
Schenkia australis	Spike Centaury	Gentianaceae	rare		Hunter Island; Three Hummock Island; Cape Barren Island; Flinders Island
Schoenoplectus tabernaemontani	River Clubsedge	Cyperaceae	rare		Flinders Island; King Island
Schoenoplectus validus	River Clubsedge	Cyperaceae	rare		King Island
Schoenus brevifolius	Zigzag Bogsedge	Cyperaceae	rare		Bruny Island
Scleranthus fasciculatus	Spreading Knawel	Caryophyll-aceae	vulnerable		Flinders Island; Bruny Island
Scutellaria humilis	Dwarf Skullcap	Lamiaceae	rare		Maria Island
Senecio psilocarpus	Swamp Fireweed	Asteraceae	endangered	Vulnerable	Flinders Island; King Island
Senecio squarrosus	Leafy Fireweed	Asteraceae	rare		Partridge Island; Bruny Island
Sicyos australis	Star Cucumber	Cucurbitaceae	rare		Inner Sister Island; Outer Sister Island
Solanum opacum	Greenberry Nightshade	Solanaceae	endangered		Deal Island; Kent Group; Prime Seal Island; Inner Sister Island; King Island
Spyridium parvifolium var. *molle*	Soft Dustymiller	Rhamnaceae	rare		Flinders Island; Cape Barren Island; Clarke Island
Spyridium parvifolium var. *parvifolium*	Coast Dustymiller	Rhamnaceae	rare		Flinders Island; Cape Barren Island
Spyridium vexilliferum var. *vexilliferum*	Helicopter Bush	Rhamnaceae	rare		Prime Seal Island; Flinders Island; Schouten Island
Stellaria multiflora subsp. *nebulosa*	Nebulous Rayless Starwort	Caryophyllaceae	rare		Deal Island; Curtis Island; Flinders Island; Vansittart Island; Little Dog Island; Swan Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Stuckenia pectinata	Fennel Pondweed	Potamogetonaceae	rare		Flinders Island; Cape Barren Island; Clarke Island
Stylidium beaugleholei	Blushing Triggerplant	Stylidiaceae	rare		King Island; Flinders Island; Cape Barren Island; Flinders Island
Stylidium despectum	Blushing Triggerplant	Stylidiaceae	rare		King Island; Flinders Island; Clarke Island
Stylidium perpusillum	Tiny Triggerplant	Stylidiaceae	rare		King Island; Cape Barren Island; Clarke Island
Taraxacum cygnorum	Coast Dandelion	Asteraceae		Vulnerable	Prime Seal Island; Flinders Island
Teloschistes flavicans	Golden-Hair Lichen	Teloschistaceae	rare		Inner Sister Island; Outer Sister Island; Babel Island
Teucrium corymbosum	Forest Germander	Lamiaceae	rare		Bruny Island
Teucrium corymbosum	Forest Germander	Lamiaceae	rare		Maria Island; Bruny Island
Thelymitra antennifera	Rabbit Ears	Orchidaceae	endangered		Hunter Island
Thelymitra atronitida	Blackhood Sun-Orchid	Orchidaceae	endangered		Bruny Island; Cape Barren Island
Thelymitra benthamiana	Blotched Sun-Orchid	Orchidaceae	endangered		Flinders Island
Thelymitra holmesii	Bluestar Sun-Orchid	Orchidaceae	rare		King Island; Bruny Island; Cape Barren Island; Flinders Island
Thelymitra improcera	Coast Sun-Orchid	Orchidaceae	endangered		King Island
Thelymitra jonesii	Skyblue Sun-Orchid	Orchidaceae	endangered	Endangered	Schouten Island; Cape Barren Island; Bruny Island
Thelymitra malvina	Mauvetuft Sun-Orchid	Orchidaceae	endangered		Hunter Island; Three Hummock Island; Robbins Island; Cape Barren Island; Flinders Island
Thelymitra mucida	Plum Sun-Orchid	Orchidaceae	rare (unofficial), listing as endangered pending		Bruny Island; Flinders Island
Thynninorchis huntiana	Elbow Orchid	Orchidaceae	extinct		Flinders Island
Tmesipteris parva	Small Forkfern	Psilotaceae	vulnerable		Flinders and King Islands
Tricostularia pauciflora	Needle Bogsedge	Cyperaceae	rare		Cape Barren Island; Schouten Island
Triglochin minutissima	Tiny Arrowgrass	Juncaginaceae	rare		Erith Island; Flinders Island; Clarke Island; Forsyth Island; King Island
Triglochin mucronata	Prickly Arrowgrass	Juncaginaceae	endangered		Vansittart Island; Flinders Island
Trithuria submersa	Submerged Watertuft	Hydatellaceae	rare		Cape Barren Island; King Island
Utricularia australis	Yellow Bladderwort	Lentibulariaceae	rare		Flinders Island; Bruny Island
Utricularia tenella	Pink Bladderwort	Lentibulariaceae	rare		King Island; Clarke Island; Cape Barren Island; Flinders Island
Utricularia violacea	Violet Bladderwort	Lentibulariaceae	rare		Flinders Island
Velleia paradoxa	Spur Velleia	Goodeniaceae	vulnerable		Bruny Island
Vittadinia muelleri	Narrowleaf New-Holland-Daisy	Asteraceae	rare		Bruny Island; Maria Island
Wilsonia humilis	Silky Wilsonia	Convolvulaceae	rare		Flinders Island

APPENDIX 2 – cont.

Species name[3]	Common name	Family[3]	Status[2] TAS	Status[2] CW	Island or group
Wilsonia rotundifolia	Roundleaf Wilsonia	Convolvulaceae	rare		Deal Island; Cape Barren Island
Xanthoparmelia microphyllizans	Lichen	Parmeliaceae	rare		Deal Island
Xerochrysum bicolor	Eastcoast Paperdaisy	Asteraceae	rare		Mount Chappell Island; Maria Island
Zygophyllum billardierei	Coast Twinleaf	Zygophyllaceae	rare		Flinders Island; Prime Seal Island

[1] Species listed were generated from the Natural Values Atlas (Department of Primary Industries, Water and Environment: DPIPWE) which relies on multiple sources both Herbarium vouchered and observational. The information was accessed on 30 October 2020. The Threatened Species Section (DPIPWE) should be consulted for up to date status, especially for those taxa whose status is listed as "pending" or "unofficial".

[2] Tasmanian status is in accordance with listings under the *Threatened Species Protection Act 1995*. National status (Status CW) refers to listings under the *Environment Protection and Biodiversity Conservation Act 1999*.

[3] Nomenclature of species and family follows de Salas & Baker (2018).

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